THE EFFECTS OF MALEIC HYDRAZIDE ON PLANT DEVELOPMENT AND ROOT QUALITY OF *RAPHANUS SATIVUS* L.

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ABSTRACT

Experiments were conducted in 1952 to investigate the effect of maleic hydrazide upon the vegetative and reproductive growth of plants. Applications of this chemical by two methods and at three stages in the life cycle of the common radish gave the following results:

1. The results were all harmful from the standpoint of upsetting normal plant processes but the opposite result was obtained from the standpoint of inducing a decrease in the rate of softening of hypocotyl tissue in storage as measured by resistance to puncture.
2. Maleic hydrazide acted as an inhibitor to the growth of plant tops and hypocotyls, and to regrowth of roots and shoots from hypocotyls subjected to a cool storage period. Treatment caused prompt cessation in the activity of the terminal meristems, and shorter plants, a lower seed pod set, and marked reductions in the total dry weight of plants.
3. The sensitivity of the plants varied inversely with the age of the vegetative or reproductive phases. That is, treatment produced the greatest abnormalities (a) to vegetative growth when applied early in the life cycle of the plant, and (b) to the reproductive processes when applied early in the reproductive

phase. The latter affected the next generation by reducing the viability of the seed.

4. Other effects which were observed but not so extensively studied were collapse of numerous palisade cells in the leaves and differentiation of a third irregular row of palisade cells.
5. In time some plants can outgrow many of the abnormal effects produced and eventually set seed.

More should be known about the mammalian toxicity of maleic hydrazide and the mechanism of its action on plants before the compound can be recommended for practical use, particularly on edible food plants. Results noted here substantiate those of other workers and suggest certain leads toward a more thorough understanding of the mode of action of maleic hydrazide on living plants.

THE UNIVERSITY OF ALBERTA

A STUDY OF THE EFFECTS OF MALEIC HYDRAZIDE ON PLANT DEVELOPMENT AND ROOT QUALITY OF *RAPHANUS SATIVUS* L.

A DISSERTATION
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
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OF MASTER OF SCIENCE

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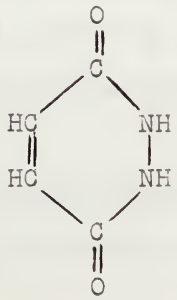
INTRODUCTION

A new discovery was announced in 1949 when Schoene and Hoffman (29) reported that maleic hydrazide had an effect upon the growth of plants. Following this publication (29) numerous investigations to determine the effects of this new chemical upon plants and plant parts were conducted. Within a short time these experiments have led authorities to classify maleic hydrazide among other synthetic growth regulating compounds. Some have considered maleic hydrazide as a general herbicide, but a number of studies have shown that maleic hydrazide is best described as a temporary plant growth inhibitor. This designation is based upon the present knowledge of the reaction of maleic hydrazide to plants. The following "Review of Literature" and the body of this report concern a consideration of the effects following maleic hydrazide application to plants.

The active ingredient contained in the available formulations of maleic hydrazide has the chemical name 1, 2-dihydropyridazine-3, 6 dione, the empirical formula $C_4H_4O_2N_2$ and the following structural formula:



Throughout the body of this report the compound maleic hydrazide is most commonly referred to as MH.

Maleic hydrazide has been formulated (1) as a diethanolamine salt, in liquid form, containing 30.0% active ingredient, designated as MH-30, and (2) as a dry sodium salt, in powder form, containing 40.0% active ingredient, designated as MH-40. The latter is the newest formulation, and it was prepared to overcome some of the deficiencies of MH-30. The MH-40 white powder is readily soluble in water, has a low rate of evaporation from the prepared liquid, can be easily washed from spray equipment with water (Zukel 35). Therefore MH-40 is a preparation of maleic hydrazide which is very easy to use as well as being more effective for application to plants than the MH-30 form.

Many desirable and practical uses for the application of maleic hydrazide to plants have been suggested recently. Most of these suggestions have been inspired by the numerous experiments which have been conducted during the past three years. The results obtained, whether through external observation or through more fundamental studies, have led inquiring minds to ask if maleic hydrazide can be employed for the following practical purposes:

1. To improve the storage qualities of fruit and vegetable produce by decreasing breakdown and preventing sprouting.

2. To act as a general herbistat when applied at specific stages of growth to certain crops or mixtures of crops. The use of directional sprays possibly may broaden this phase of influence.
3. To act as a temporary growth inhibitor of entire plants or plant parts.
4. To create artificially dwarf fruit and ornamental trees and shrubs.
5. To increase the sugar concentration in plants.
6. To create artificial male sterility in some monoecious plants such as corn.
7. To prevent the formation of undesirable fruit upon certain ornamental trees.

Other suggested uses could be listed but these indicate the diverse nature and the economical possibilities that are being considered for the use of the chemical maleic hydrazide.

Since experimentation on the influence of maleic hydrazide upon plants has recently become popular and has been carried on by numerous investigators, many of the results reported to date have been comprised largely of visual symptoms and comparatively few have been of the fundamental type. Although investigations of the fundamental type require more time and resources they will be of more value in an effort to obtain accurate answers to the above questions concerning the possible and logical

uses of MH. For example, it would seem wise to secure more complete and precise information on the toxicity of maleic hydrazide to animals than is published at the present time before recommendations on the application of this chemical to food plants are made to an unsuspecting public. Plant breeders and seed stock producers also would appreciate more knowledge than they have available regarding possible heritable effects of maleic hydrazide. Answers to the two preceding important questions require not only external or superficial observations but accurate, detailed, and painstaking investigations of a more basic nature than many of those thus far reported.

In line with the current interest in the possibilities of using MH for practical purposes, the research reported herin was initiated to study the effects of maleic hydrazide on the growth, hypocotyl quality and the germination of the T_1 generation of the common radish. This was an effort to gain information which would add to fundamental knowledge of the effects of various treatments to radish plants. It was hoped that from the results obtained answers to the questions noted earlier might be provided.

LITERATURE REVIEW

The purpose of the following survey of literature is to consider briefly some of the most important effects of maleic hydrazide upon the growth and quality of plants.

Various definitions of plant growth are recognized. Meyer and Anderson (24) state that the term "growth" is popularly employed by botanists to designate the complex of processes involved in the more or less continuous increase in size and production of new organs throughout the life history of the plant. Such a concept of growth is suitable for the purpose of this study.

A definition of quality in fruits or vegetables may be stated as the possession of those component characteristics which make the product more or less desirable for use.

Of the two common formulations of maleic hydrazide, MH-40 has certain qualities which MH-30 does not possess. For example MH-40 contains a wetting agent and sticker (35). The addition of a wetting agent to MH-30 is necessary for maximum plant response (35). Furthermore the sodium salt is reported to have a lower mammalian toxicity than the diethanolamine salt (35). Otherwise the essential biological properties of MH-30 and MH-40 are for all practical purposes the same. In the following discussion of

the biological properties the active ingredient maleic hydrazide (MH) is considered.

Biological Properties of Maleic Hydrazide

A few of the most important biological properties of maleic hydrazide may be listed as follows:

1. It is a chemical substance which is toxic to animal (1) and plant tissues when absorbed, but is relatively inactive when not absorbed. To many plants the toxicity of MH is sufficient that it has been successfully used as a general herbistat (28).
2. It temporarily inhibits growth when applied to plants at low dosages (35).
3. It is readily absorbed by roots and leaves, and is translocated in both an upward and downward direction in plants (Linder as reported by Zukel 35). The MH-30 form requires about two days to be absorbed by plants and any rain or heavy dew occurring within this period may reduce the response (35).
4. The presence of MH can be detected in vegetable and animal matter by an analytical method sensitive to a fraction of a part per million (33).
5. The response of MH is greatest at a minimum dosage when applied to young plants at the start of the growing season (3) (34) (35), and the response varies with the dosage used (3).

6. It is reported that MH used at low or moderate rates has a short residual effect in the soil (35).

The Action and Effects of Maleic Hydrazide Upon Plants

The mechanism of the action of maleic hydrazide upon normal plant processes is as yet unknown (28). Publications which might have a bearing on this problem are reviewed first in the following paragraphs.

Experiments show that maleic hydrazide is antimitotic in its action rather than affecting cell elongation. According to Zukel (35), Greulach found that no concentration of MH inhibited growth of etiolated bean hypocotyl, indicating that MH inhibits cell division rather than cell elongation. Observations made on the root growth of Southport yellow globe onions lead Greulach and Atchison, as reported by Zukel (35), to conclude that MH inhibited mitosis and cell division in proportion to the concentration used. Darlington and McLeish (6) found no mitosis for two days following the immersion of roots of *Vicia faba* in solutions above .0005M. maleic hydrazide for 24 hours. Lower concentrations did not stop mitosis, but rather showed breakage of chromosomes at mitosis.

Other observations support the conclusion that MH acts in opposition to the natural or synthetic hormones in plants. Using four different inhibitory levels in standard

pea and straight growth tests Leopold and Klein (22) found that indoleacetic acid completely overcame MH inhibition. Hitchcock and Zimmerman (18) observed that combinations of 2,4-D and MH produced additive and antagonistic effects. Application of a mixture of 0.2% MH plus 0.1% 2,4-D showed a clear-cut antagonism (Currier 5). Pre-harvest foliage sprays of MH consistently retarded the softening rate of fruit on the tree and during storage at 74° F after harvest, whereas sprays of 2,4,5-T and 2,4,5-TP stimulated the softening rate of fruit (Smock as reported by Zukel 35).

Investigations on a number of plants indicates that MH inhibits respiration. Naylor and Davis, as reported by Zukel (35), studied the respiration response of root tips of peas, sunflowers, tomato, corn, barley, oats and wheat to maleic hydrazide. They found respiration at pH 6.0 was not appreciably affected, but at pH 4.0 marked inhibition resulted with the degree of inhibition increasing with the concentration of MH. Observations made on the storage organs of plants following pre-harvest foliage sprays also suggest ~~ax stextexx~~ that MH inhibits respiration (30) (Wittwer and Hansen as reported by Zukel 35).

According to Zukel (35) Naylor and Davis state that MH possibly exerts its influence on growth by inhibiting respiration perhaps affecting the normal function of the dehydrogenase enzymes. Isenberg et al. (20) states

that MH sprayed on the foliage of onions affects respiration through the partial inactivation or inhibition of one or more of the dehydrogenases.

MH may affect the carbohydrate metabolism causing an accumulation of carbohydrates and the appearance of anthocyanins. Greulach (15) found that the translocation of starch from leaves of treated tomatoes, beans and sunflowers was extremely slow. Currier (5) reported that MH treated barley showed a lower fresh weight but a higher dry weight than the controls and that was due to accumulation of fructosan. Analysis of an exudate which appeared on the leaves of growing barley following treatment showed that sucrose was the predominant substance present. Naylor (27) reported an accumulation of invert sugar in both shoots and roots of all treated maize seedlings. The amount of invert sugar accumulated depended upon the concentration of MH used. Thirteen times as much invert sugar was found in the tops of seedlings treated with 4000 p.p.m. MH and twice as much in the roots as compared with the controls. Quantitative analysis of plants harvested 20 days after treatment indicated that MH had little effect on the dextrose accumulation in leaves. Less dextrose was present in the roots of treated plants than in the controls. According to Zukel (35) both Kirie and

Mikkelsen, and Wittwer and Hansen found foliage sprays of MH produced a significantly higher per cent sucrose in sugar beets. Another common response following foliage treatments of MH is anthocyanin pigmentation which might logically result from carbohydrate accumulation in the leaves (Crafts 3). This increased pigmentation has been noted by a number of investigators (11) (12) (32) (34).

MH has been considered to differ from most growth controlling chemicals in that it has been reported to cause only inhibition of growth with no formative effects (28) (Wittwer as reported by Zukel 35). However other reports indicate that MH causes formative effects on sugar beets, radish, cotton seedlings and Croft Easter Lilies (3) (9) (19) (31). An explanation for such a difference among plants has not been found in the literature.

In the foregoing paragraphs what appear to be the most important hypotheses on the mechanism of the action of MH have been presented. They should be considered quite tentative and subject to revision as more data are secured. No doubt such hypotheses will provide a basis for the interpretation of most of the numerous superficial observations which are reported in the literature.

For the following reasons the external observations of the effects on plants following treatment with MH will not be discussed in detail: (a) many of the external

observations reported would be those which may be expected to follow as a result of the more basic type of observation already described; (b) a positive interpretation for the basic or causal influence responsible for most external observations cannot be given until the mechanism for the action of MH in plants is known. However the following brief comments will be useful for later discussion.

The temporary inhibition of plant growth is perhaps the most common observation made following moderate application of MH (2) (5) (12) (13) (14) (21) (35). Although a delay in the vegatative development is usually accompanied by a similar inhibition in the reproductive development, in certain tree fruits it has been found difficult to delay flowering without producing injury (35). Zukel (35) states that Denisen obtained highly significant increases in yield in one variety of strawberry the spring following an inhibition of runner development caused by MH treatment. On the other hand the results of other experiments with strawberries have resulted in significantly reduced yields following foliage applications of MH (17). However if MH treatment causes inhibition of growth the most common result is reduced yield as measured by the vegetative or reproductive parts of the plants (2) (12) (16) (19).

Improvement in the storage qualities of certain crops can be attained by the use of pre-harvest foliage

sprays of MH. Such observations have been made in apples, onions, potatoes, lettuce, sugar beets, carrots, beets, parsnips, turnips, and rutabagas (30) (Johanessen and Oebker, Kennedy and Smith, Kosar and Thompson, Peto et al., Wittwer et al., Wittwer and Hansen, Wittwer and Paterson as reported by Zukel 35). In the root crops sprout and root growth in storage was inhibited. Zukel (35) has summarized results and recommendations, prepared by Wittwer and Paterson, for the treatment of onions, potatoes and root crops. Reduced quality of snap beans was noted (16) following a spray application of MH made at different stages in the development. This observation indicates that for some crops a reduction in quality may result rather than an improvement in quality.

A varietal difference in response has been noted in apples (30), but in onions a number of varieties and hybrids responded similarily to treatment (Wittwer and Paterson as reviewed by Zukel 35). The time of spraying prior to harvest for the best results was found to be critical for onions, but Zukel (35) states that Wittwer and Hansen found that the dates for spraying sugar beets could vary widely. The degree of inhibition may vary among plant species and within the same species depending upon the dosage used and the age of the plants at the time of treatment (35). Since young plants treated at the beginning of the growing season seem to be the most susceptible (15) (35) the amount of growth may be expected to be reduced the most if treatment

is made early in the season.

Other experiments indicate that MH acts in the following ways:

1. As a general herbicide to certain plants particularly if applied at an early stage of growth (3) (28) (35).
2. Causes chlorosis in leaves or increases the concentration of anthocyanin pigments (4) (7) (11) (12) (23).
3. Effects sterility in flowers (8) (25) or prevents the normal setting of fruit or seed (Chadwick et al., Grigsby, Miller and Erskine as reported by Zukel 35).
4. Stimulates the rate or speed of reproductive development following treatments to young plants (2) (3).
5. Produces dwarf fruit trees (White according to Zukel 35).

In some cases plants may outgrow many of the formative and physiological effects of MH (5) (10) (13) (14).

Other effects of MH could be given, but reference has been made to the most important observations. More detail may be obtained on the results of experiments conducted with maleic hydrazide from 1949 to 1952 by reference to a "Literature Summary on Maleic Hydrazide"[1] as compiled by Zukel (35)

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[1] This publication may be obtained from Naugatuck Chemical Division, U. S. Rubber Company, Bethany 15, Connecticut, U. S. A.

MATERIALS

The common radish was the organism chosen as the test plant because it is a root crop with a short life cycle, thus allowing several crops to be grown in a relatively short period of time.

The formulation of maleic hydrazide used for all treatments was Naugatuck MH-40. This formulation prepared as a dry water soluble powder, with sticker, contains 40.0% of active maleic hydrazide.

METHODS

The plant material for all the experiments came from five separate plantings or trials. Titles of these trials together with the dates of sowing and seed material are as follows:

	Date of sowing 1952	Seed Material
A. Soil Application Trial	May 13	Cincinnati Market
B. Greenhouse Trial	May 23	Scarlet Globe
C. Field Trial	May 27	Scarlet Globe
D. Quality Trial	Sept. 22	Scarlet Globe
E. The T_1 Generation Trial	Oct. 23	Scarlet Globe from Field Trial treatments.

Only the Field Trial was grown out of doors. The other trials listed above were grown entirely in the greenhouse in flats containing soil of medium texture.

Applications of MH-40 at three stages in the life cycle of the plant were performed in this study, and for each two methods of treatment were employed as listed in Table 1.

Soil Application, Greenhouse and Field Trials

The procedures used in the Soil Application, Greenhouse and Field Trials were:

(1) Pre-emergence Stage

(a) Soil Applications. Maleic hydrazide was applied at 30, 20 and 10 pounds of active ingredient per acre to greenhouse flats two days after planting the Cincinnati Market radish.

(b) Seed Soaking Treatments. Seed of Scarlet Globe radish was soaked for varying periods of time in solutions of maleic hydrazide[1] as follows:

0.01% for ½ hour,

0.02% for 2 hours,

0.20% for 2 hours,

1.00% for 2 hours.

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[1] Rates are stated either as maleic hydrazide pounds per acre or concentration of active ingredient in water solution.

The seed was rinsed well in water after soaking the required time and then immediately planted in greenhouse flats.

(2) Three to Six Days Prior to Stage of Market Size of Hypocotyl

(a) Early Foliage Treatments. Early foliage sprays of maleic hydrazide were applied at 0.01, 0.05, 1.0, 2.0 and 4.0 pounds per acre to the Greenhouse Trial and 0.5, 4.0 and 8.0 pounds in the Field Trial. All rates were applied in 66 gallons of water per acre.

In the Field trial a negligible amount of MH-40 reached the soil. In the Greenhouse Trial absorbent paper was used to catch any falling spray and later removed from the flats. The time of application was approximately three and six days prior to the marketable stage of hypocotyls for the Greenhouse and Field Trials respectively.

(b) Early Root Treatments. In the Greenhouse Trial solutions of 0.1, 0.5, 4.0 and 10.0 pounds per acre of maleic hydrazide were pipetted to the region of root growth of the individual plants. In the Field Trial the MH-4o solution was applied at the rate of 4, 10 and 20 pounds per acre delivered into a shallow furrow made on each side of the plot rows.

(3) Stage of 50% Full Bloom of Controls.

(a) Late Foliage Treatments. Applications of maleic hydrazide were made as late foliage treatments in 66 gallons of water at the time when the control plants were at the stage of an estimated 50% full bloom. Foliage sprays were directed horizontally towards the foliage below that portion of the plant which was bearing most of the flowers so that essentially no MH-40 was applied directly to the flower buds. The same rates as those applied to other plots at market size stage were applied at this stage; namely 0.1, 0.5, 4.0 and 10.0 pounds per acre, with the use of spray shields in the Greenhouse Trial; and 0.5, 4.0 and 8.0 pounds per acre in the Field Trial. In the Field Trial alternate guard rows were present and so shields were not needed.

(b) Late Root Treatments. Maleic hydrazide was applied as in the early treatment. The same procedures and the same rates were employed in late root treatments as were used in the early root treatments. In the Greenhouse Trial 0.1, 0.5, 4.0 and 10.0 pounds of MH per acre was pipetted to individual plants. In the Field Trial 4, 10 and 20 pounds per acre were delivered from a nozzle into a shallow furrow on each side of the plot row.

Maleic hydrazide applied as root treatments

was made readily available to the roots in the Greenhouse Trial by having the medium in the flats thoroughly moist before treatment and in the Field Trial by adding water to the furrows a short time after the chemical was applied. No moisture came in contact with the plant leaves within a period of 30 hours after foliage sprays were made.

Quality Trial

The Quality Trial was designed to study the effects MH treatment had upon hypocotyl quality. The trial consisted of six plots treated and the same number not treated. The treatment was a foliage spray of maleic hydrazide applied at 4.0 pounds per acre eight days before hypocotyls reached market size. Each plot contained 24 plants.

Eight days after treatment all the plants were lifted, washed, and topped. The hypocotyls that were not used immediately for tests were packed in sterilized peat moss and placed in cool storage where the temperature remained near 4° C.

Tests were made at three separate dates, and eight hypocotyls were used at each time as follows:

(1) At harvest time a total soluble solids determination,

(2) After hypocotyls were kept in cool storage for 18 days a total soluble solids determination plus a dynamometer

test to measure resistance to puncture,

(3) After hypocotyls were kept in cold storage for a further storage period of 36 days a second dynamometer test.

T_1 Generation Trial 1952-1953

The "T_1 Generation Trial" was conducted to make a comparative test of differences in germination of seed as influenced by application of MH-40 to parent plants. All the treatments in the Field Trial which produced seed were compared as separate treatments in the T_1 Generation Trial. Thus the rates listed in Table 1 for this trial are simply treatments identified by the rate at which MH-40 was applied to the parental plots.

Summary of Methods

The method of treatment and the amount of active maleic hydrazide applied at each date of treatment or stage of growth for each trial are listed in Table 1.

Table 1. Summary of MH treatments[1] Under Various Conditions

Pre-emergence		Foliage		Root	
Soil	Seed	Early	Late	Early	Late
(A) Soil Application Trial (one replicate)					
ttmts. lb./A					
10					
20					
30					
(B) Greenhouse Trial (four replicates)					
ttmts. % conc. hours		ttmts. lb./A	ttmts. lb./A	ttmts. lb./A	ttmts. lb./A
0.01/½		0.1	0.1	0.1	0.1
0.02/2		0.5	0.5	0.5	0.5
0.20/2		1.0	- -	- -	- -
1.00/2		2.0	2.0	4.0	4.0
0.00/2		4.0	4.0	10.0	10.0
sown dry		0.0	- -	- -	- -
(C) Field Trial (four replicates)					
		0.5	0.5	4	4
		4.0	4.0	10	10
		8.0	8.0	20	20
		0.0	- -	--	--
(D) T_1 Generation Trial (four replicates)					
		0.5	0.5	4	4
		4.0	4.0	10	10
		- -	- -	20	20
		0.0	- -	--	--
(E) Quality Trial (six replicates)					
		0.0			
		4.0			

[1] Rates are given as MH pounds active ingredient per acre or as per cent concentration of MH active ingredient per volume of water.

Experimental Designs

Replication. The Soil Application Trial was preliminary in nature, and therefore no replication of the three rates of application was made. The other trials with Scarlet Globe radish were set up in the randomized block design with four replications except in the Quality Trial where six replications were used. In the Greenhouse Trials each replication consisted of five major methods of treatments of four rates each. With two controls this made a total of 22 plots per replicate. For any test in which the material was taken from the Greenhouse Trial the use of four replications and the randomized block arrangement was maintained. The Field Trial contained four methods of treatment at three rates each plus a control, making a total of 13 plots per replicate.

Guards. Plant guards were not used in the trials grown in the greenhouse because flats were used as containers. Glass partitions were tightly fitted to separate plots where soil treatments were involved. A moveable shield was employed to confine the spray to the desired area. In the Field Trial alternate rows of the test were guard rows. On the end of each plot there was also two feet of guard row. This provided adequate protection against drift since applications were made during calm periods.

Thinning. At the time hypocotyls were harvested a process of thinning was also carried out. This allowed sufficient space for other plants to develop to maturity and left no undesirable gaps in the plots. Each plot in the Greenhouse Trial consisted of twelve plants until the time of market size. At this date six plants were harvested and six remained to comprise the population which was observed until the end of the normal life cycle. In the Field Trial a similar process of thinning was used in obtaining yield data at the time hypocotyls were at market size. Alternate plants were removed.

Methods of Collecting the Data

On Plant Growth. To measure the growth of various portions of the plant the tops were cut off one cm. above the hypocotyl. Weights of the hypocotyls included this small stem portion and the main tap root which would remain attached after harvesting by the normal procedure of pulling. Records on the behavior of radish kept in cool storage were taken to show the renewed top growth and root regrowth. Top growth made above the point where the tops were first cut off was weighed as new growth. During the cool storage period new roots grew from the original tap root. The renewed root growth was measured by carefully lifting each hypocotyl from the vermiculite[1] and weighing after shaking off any of the

[1] Vermiculite is a heat expanded form of mica used as the inert medium for storing hypocotyls in this experiment.

medium which was not held firmly by the new rootlets. This proved to be an excellent way to measure the root growth activity exhibited among the various treatments.

Quality. (a) Tissue Breakdown. A dynamometer was used to measure the firmness of the tissues of the radish hypocotyls after a cool storage period of six weeks. This instrument measures the resistance to puncture in pounds per square unit area of the head of the plunger. (b) Soluble Solids Content. The determination of the total soluble solids of hypocotyls was made with a hand refractometer accurate to approximately 0.2 per cent reading. By this method determinations could be made quickly without danger of evaporation nor of any change taking place inside the hypocotyl following the time these were removed from cool storage.

T_1 Generation. The procedure for the collection of seed for the T_1 Generation Trial was based upon the following observation. Since the plants were growing compactly in each row, spraying could not insure application of maleic hydrazide in precisely equal amounts to each plant. However by choosing plants most typical of the treatment concerned from which to obtain the seed material, the variation due to dosage of MH received was minimized. The sample of seed for each treatment was gathered from four plants (two plants from two replicates). Pods from each plant were chosen at random and this sample was threshed and well mixed before

used in further tests. Emergence data were collected one month after sowing.

Methods of Analyzing the Data

The data were analysed to determine the significant effects of MH-40 by means of the analysis of variance or by the "t" test if there were only two treatments involved.

Separate analyses were made for each trial. A test was made to determine if there was association of the standard deviation with means for any one set of data. Where this type of association was found logarithmic transformation was used.

Climatic Influences

The climate during the season of 1952 was excellent for the outdoor culture of radish. For the Greenhouse Trial the environmental conditions were largely controlled. Therefore in both trials the number of plants per plot and the resulting growth were very uniform. A long frost free season and good growing conditions until late in September allowed extra time for maximum plant development. In the Greenhouse Trial watering was gradually reduced during a period of three weeks to induce maturity of the plants at about the same time and in similar manner to that which would be accomplished naturally for plants growing out of

doors.

Growth of radish in the Quality Trial and the T_1 Generation Trial was slow due to less favorable conditions of light and heat in the greenhouse in the late fall and winter months.

Other Influencing Factors

During the cool storage period of hypocotyls obtained from the Greenhouse Trial a disease caused by a fungus, one of the Phycomycetes identified as *Phytophthora parasitica*, began to infect some of the hypocotyls. Upon finding that control measures would be difficult and the numbers of hypocotyls would become reduced with time, tests were terminated at the end of a period of six weeks in cool storage.

RESULTS

The work of this thesis is presented under three main headings, namely; Treatment Effect on Plant Development, Treatment Effect on Hypocotyl Quality and Treatment Effect on the T_1 Generation. The first two of these headings are in turn reported under two subheadings, viz.; (1) Visual Observations and Quantitive Observations, (2) Firmness of Hypocotyl Tissue and Soluble Solids Content, respectively. Most of the results have been presented photographically and graphically. The graphs shown in Figures 33 to 41 have been based directly upon corresponding original data given in the Appendix tables presented in pages i to xvii. Certain abbreviations and symbols have been used in the graphs. Similarily abbreviations have been used with the pictures, Figures 1 to 32, to describe the treatments represented. Table 2 contains a key to the abbreviations used in pictures and graphs.

Table 2. Key to Abbreviations Used to Indicate the Treatments[1] of MH-40 Applied.

A. In graphs Figures 33 to 40.

Fd. = Field Trial.

Gr. = Greenhouse Trial.

S.D. = Significant difference from Control[2].

x = No significant difference from control.

⌒ = Significantly different from control at 5% level.

○ = Significantly different from control at 1% level.

___ = Greenhouse Trial.)
) Where both occur together.
__ __ = Field Trial.)

----- = Any other distinction - (each is labelled).

B. In pictures Figures 1 to 32.

1st F = early foliage.

2nd F = late foliage.

1st R = early root.

2nd R = late root.

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1 See Table 1 for a list of rates used in treatments applied.
2 In the Greenhouse Trial significant differences were taken from the control - seed soaked in water two hours.

Treatment Effect on Plant Development

1. Visual Observations

Certain effects on the growth of the plants soon became evident following the pre-emergence application of MH-40 in the Soil application Trial and in the seed treatment of the Greenhouse Trial. With both increases in the rate of application of the soil treatments from 10 to 20, and 20 to 30 pounds per acre there was a reduction in the number of plants which emerged. Compared with the control plots emergence was delayed as much as seven days. The emerged plants gradually became chlorotic and about 95% died about one month after sowing without having passed the seedling stage. These plants were photographed 20 days after sowing and were shown in Figure 1.

The results from the 1.0%/2 hours rate of the seed soaking treatments of the Greenhouse Trial were remarkably similar to those obtained from the Soil Application Trial. This is illustrated in Figure 2, and should be compared to Figure 1.

Plants from both the Soil Application Trial and the 1.0%/2 hours seed treatment of the Greenhouse Trial were lifted and washed. Examination revealed a greater inhibition of growth in the roots than in the shoot portion for both methods of treatment. This result

can be seen from the photographs of the exposed plants Figures 3 to 5.

Figure 1. The three plots in the foreground show the drastic effect 20 days after application of MH-40 to the soil at 10, 20 and 30 lb./A compared to the control in the background. Many of the affected seedlings are barely above the soil surface. After a meager existance for some two weeks the cotyledons began to yellow at the margin and slow death followed. Soil Application Trial.

Figure 2. The extremely dwarf and weak seedling plants of the two plots in the foreground resulted from MH-40 treatment on seed at 1.0%/2 hours. Contrast with the normal development of the control plots in the background. All plants were sown 21 days prior to the date of photographing. Note the similarity to the effects of the soil treatments shown in Figure 1. Greenhouse Trial.

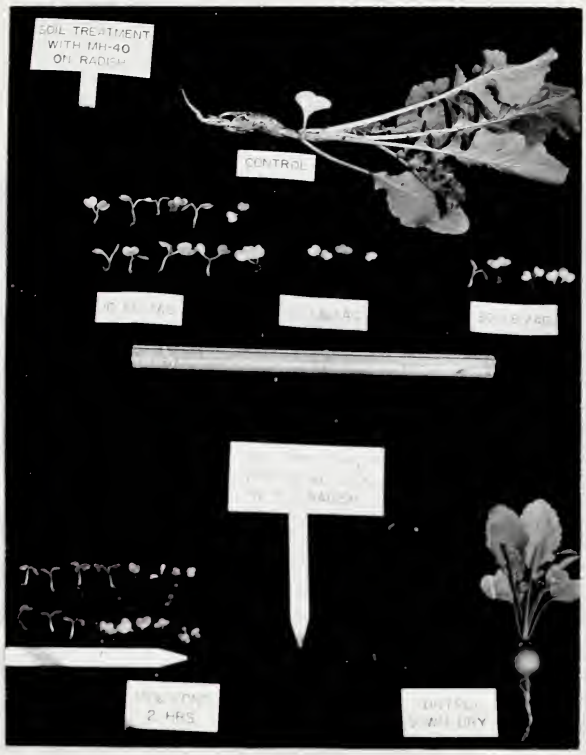

Figure 3. Below the control, top center, seedlings of Cincinnati Market radish from soil treatments of MH at 10, 20 and 30 lb./A are shown from left to right pictured 29 days after sowing. Note similarity in the effects of the 1.0%/2 hours seed treatment (lower left) made on the Scarlet Globe variety as compared with its control (lower right). Soil Application and Greenhouse Trials.

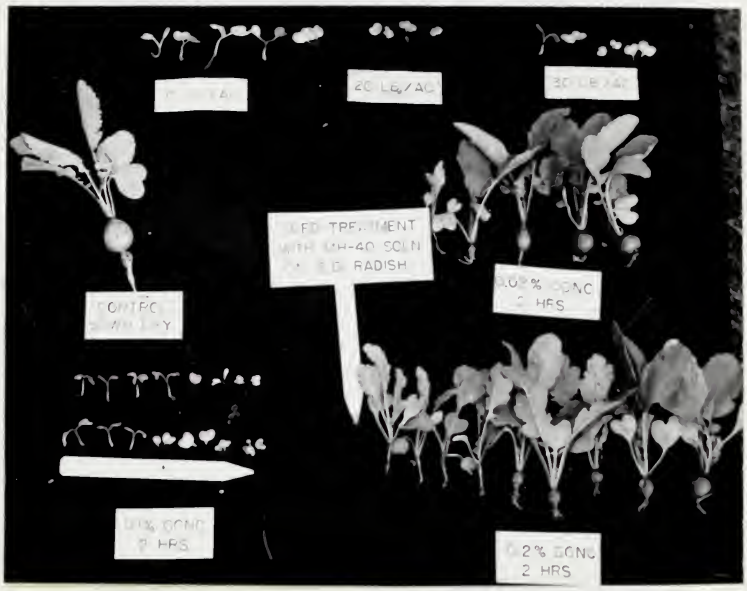

Figure 4. Compare the seedlings from the soil treatments (along the top), with Scarlet Globe radish seedlings from the 1.0%/2 hours (lower left), the 0.02%/2 hours (center right), the 0.2%/2 hours (lower right) seed treatments and the control (center left). Soil Application and Greenhouse Trials.

Approximately ten per cent of those plants left growing in the plots receiving the 1.0%/2 hours seed treatment managed to remain alive throughout the entire growing season. Only some six per cent of these plants developed a flower stalk and bore two or three small seed pods. One of these plants is shown in Figure 24.

As shown in Figures 4 and 5 the seed soaking treatment of 0.02%/2 hours caused much less severe effects, but inhibition of growth was quite marked in certain plants. This variation in effect upon the plants grown from seed soaked in 0.2 and 0.02% solutions for two hours is clearly seen in these photographs. Inhibition of vegetative development was readily visible in the 0.2%/2 hours seed treatment throughout the entire season. The quantitative results noted later in Figures 33 and 40 support this statement. There was a smaller percentage of the plants showing severe retardation in growth from the 0.02%/2 hours treatment as compared to the 0.2%/2 hours seed treatment. For the 0.02% treatment quantitative data showed that growth was not significantly different from the control with the exception of renewed root growth (Figures 7 and 36) as described later.

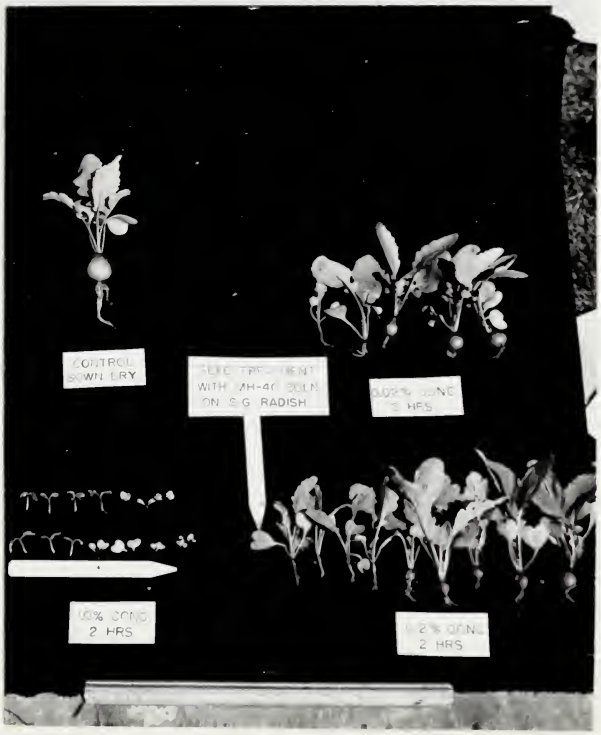

Figure 5. Typical plants from the MH-40 seed treatment on Scarlet Globe radish, pictured 29 days after sowing. Note stunted tap root development of treatments on the right. Over 95% of the plants from seed soaked in 1.0%/2 hours did not develop further than the stage shown (lower left). Greenhouse Trial.

Figure 6. The results 29 days following four seed treatments of MH-40 may be compared with the control plots (background and center). The 1.0%/2 hours seed treatment was described in Figure 2. Delayed development and abnormally elongated and wrinkled leaves are evident in the 0.2%/2 hours treatment (lower right). No visible effects of the 0.01%/½ hour treatment were evident (plot near upper left). See Figure 5 for details of the effects of 0.02%/2 hours treatment (plot near upper right). Greenhouse Trial.

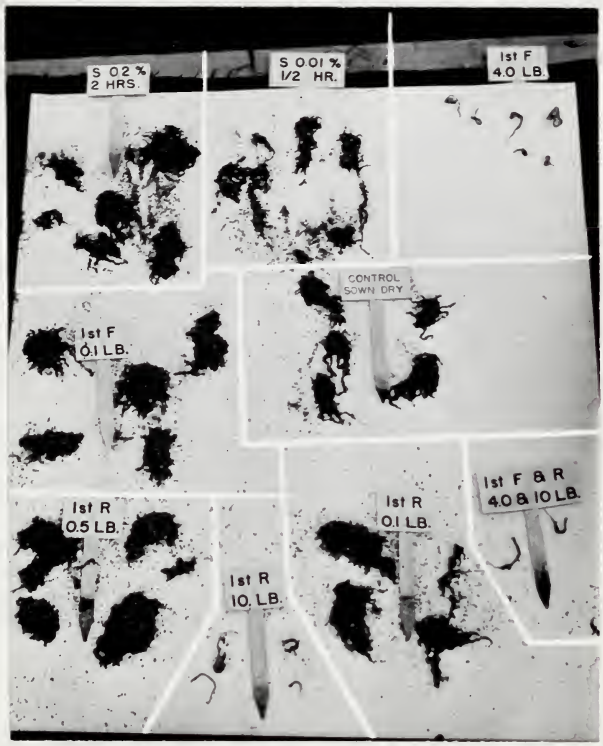

Figure 7. Roots of radish newly cut from base of hypocotyl plus vermiculite media firmly held by new rootlet growth made during 41 days period in cool storage at 12° C. Renewed root growth was nil following early foliage treatment at 4.0 lb./A (upper right), early root 10 lb./A (second from lower left), and the combined early foliage and root at 4.0 and 10.0 lb./A respectively (lower right). In contrast, the amount of new rootlet development in the remaining treatments is similar to that of the control (right center). Weight of roots and vermiculite are graphed in Figure 36. Greenhouse Trial. (See Table 2 for description of treatments.)

Differences between the control plants and those receiving the 0.01%/½ hour seed treatment were not large enough at any stage of growth to be observed visually. Figures 33, 34, 36 and 40 illustrate such quantitative differences as were measured.

The visual results from the early foliage treatments for the Greenhouse and Field Trials can be most conveniently given together. Inhibition in the growth of the plant tops promptly followed the early foliage treatments of 2 and 4 pounds per acre Greenhouse Trial and 4 and 8 pounds per acre in the Field Trial. The difference in growth between the controls and these treatments was apparent four to five days after spraying and was quite obvious from one week to more than three weeks following the date of spraying.

In the Greenhouse Trial the effects of the MH-40 were so drastic from the 4.0 pound treatment that approximately 30% of the plants slowly died before the date of harvest, September 16, and there was no appreciable amount of growth made by the plants which were living before the end of the growing season, 15 weeks after spraying. These results are demonstrated by photographs in Figures 8, 27 and 28 and by graph in Figures 33 and 40. Only a few plants in the 2.0 pound treatment of the Greenhouse Trial died. The plants

appeared to be as severely retarded as those in the 4.0 pound treatment for a period of some four to five weeks. After this time weak lateral growth from the basal portion of the shoot developed. This is shown in Figure 28. The same observations were made in the Field Trial for the 8.0 and 4.0 pound treatments. Approximately ten per cent of the plants died following the 8.0 pound treatment and 5% died following the 4.0 pound treatment. In both treatments the secondary cause of the death of these plants was disease. Weak shoot growth resumed from below the original terminal approximately three weeks after spraying. The time at which growth resumed in the 8 and 4 lb. treatments was approximately the same. This observation is supported by the quantitative data on the number of days from emergence to bloom stages as noted later under the heading, "Quantitative Observations".

The late foliage sprays of 2 and 4 pounds per acre in the Greenhouse Trial and of the 4 and 8 pounds per acre in the Field Trial produced less marked effects upon the vegetative growth than upon reproductive growth. Nevertheless there was marked inhibition in lateral growth and further vegetative development was very meager and weak during the following seven weeks of normal growing season. This is shown in Figures 8, 23, 24, and 31, and by quantitative data described later.

The effects upon vegetative and reproductive growth of MH-40 applied at the same time and at the lighter rates of treatment in either the Greenhouse or Field Trials were less pronounced than was caused by the heavier rates already described. Therefore the description of the results shown photographically in Figures 7, 14 to 21 and 33 to 41 provides sufficient elaboration of the effects obtained for these lighter rates of treatment.

Figure 8. Typical development of plants growing in two plots divided by the ruler. In the foregroun d the top growth of the six plants is very small 63 days following the early foliage treatment at 4 lb. per acre. The sparse development and short axillary branches characterize the plants 24 days following the second foliage treatment at the same rate. Greenhouse Trial.

Figure 9. The plot below the arrow on the left received a 4.0 lb./A early foliage application of MH-40 37 days prior to photographing. The plot below the arrow on the right received an 8.0 lb./A early foliage application. In the center is a control plot. Note the lack of flowering in these treated plots as compared to the control. Field Trial.

Figure 10. Compare the small amount of spindly top growth 37 days following the 8.0 lb./A treatment with the dense and sturdy top growth of the control plot on the left. Field Trial. (Total plant weight is illustrated graphically in Figure 39.)

Figure 11. Abnormal development of leaves and stems, and lodging are shown 37 days following 8.0 lb./A early foliage treatment. Leaves are elongated and leathery in appearance, stems are succulent, weak and are lodging at the right of the sign. Field Trial. (A visual rating on lodging is graphed in Figure 37.)

Photographs Illustrating Final Plant Development September, 1952

Photographs of entire plants from treated and control plots were taken at the end of the growing season in order to show the most noticeable effects of application of MH-40 on the amount and type of growth and development. Compare these visual records with quantitative data on plant height and weight illustrated by graphs in Figures 33 to 41. Abbreviations used to identify treatments are summarized in Table 2.

(a) Photographs of Typical Plants 105 Days After Sowing. Field Trial

Figures 12 to 23 inclusive are photographs of plants representative of treatments from the field trial made 105 days after planting. On the left in each of the following pictures the same control plant is present. On the right side is a plant typical of a plot receiving the treatment indicated on the white identification card.

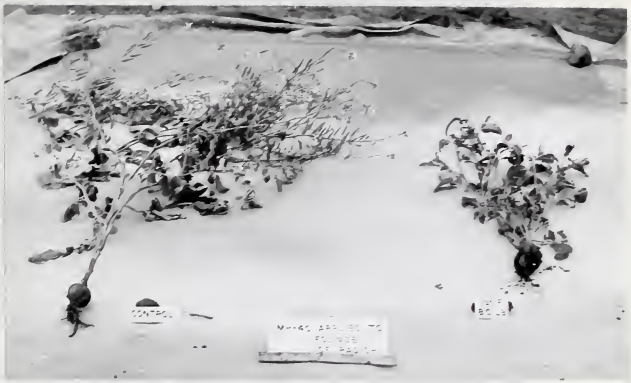

Figure 12. Note the very dwarfed plant with numerous succulent stalks arising from the hypocotyl, elongated leathery leaves, lack of flowers and seed pods, and stunted tap root development resulting from 8.0 lb./A early foliage application of MH-40 one week before the market size.

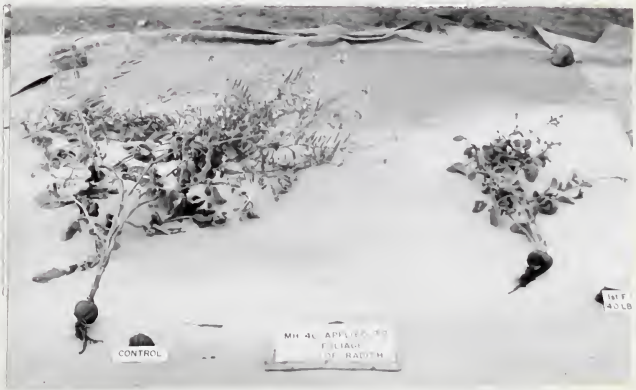

Figure 13. The 4.0 lb./A early foliage treatment of MH-40 also resulted in abnormal leaves, very few flowers, absence of seed pods, and some increase in the number of stems.

Figure 14.

Figure 15.

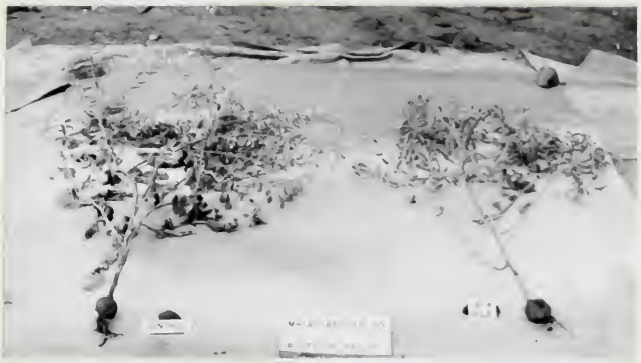

Figure 16.

Figures 14 to 16. Plant development following 0.5 lb./A early foliage, 20 and 10 lb./A early root treatments of MH-40 did not appear to differ much from that of the control pictured in each of figures 14 to 16 respectively with the exception of larger upper leaves produced in the former treatment. For accurate comparisons see data graphed in Figure 39.

Figure 17.

Figure 18.

Figure 19.

Figures 17 to 19. Visible effects of treatment at 4.0 lb./A early root, and 20 and 10 lb./A late root treatments of MH-40 were very slight. For more accurate comparisons see Figure 39.

Figure 20.

Figure 21.

Figures 20 and 21. Little visible difference in plant development resulted from the 4.0 lb./A late root treatment (Figure 20). In the 0.5 lb./A late foliage treatment (Figure 21) there were larger upper leaves as compared to the control. Figure 39 shows that there were significant quantitative differences compared with the control in the final plant weight.

Figure 22.

Figure 23.

Figures 22 and 23. Large and similar reductions in further vegetative and reproductive development followed late foliage applications of MH at 8.0 lb./A (Figure 22) and the 4.0 lb./A (Figure 23). Reduced reproductive development was followed by earlier maturity in both treatments.

(b) Plants Photographed 115 Days After Sowing. Greenhouse Trial

The same two control plants were photographed in each of the following pictures. The plant on the left is representative of the control plots planted with seed soaked for two hours in distilled water; the plant on the right is representative of the control plots planted with seed not soaked. The center plant illustrates the typical effects of the treatment involved. Figures 24 to 27 show the effects of maleic hydrazide as seed treatment. Figures 28 to 32 illustrate the effects of the heaviest rate of the early foliage, early root, late foliage, and late root applications of maleic hydrazide.

Figure 24. A typical extremely dwarf plant resulting from MH-40 treatment on seed at 1.0% for 2 hours.

Figure 25. MH-40 treatment on seed at 0.2% for 2 hours also dwarfed the plants seriously.

Figure 26. Seed treatment in a very dilute solution of MH-40 (0.02%/2 hours) did not significantly curtail vegetative or reproductive growth as illustrated in Figure 41.

Figure 27. Further reduction in MH-40 concentration and reduced time of exposure (0.01%/½ hour) allowed almost normal development.

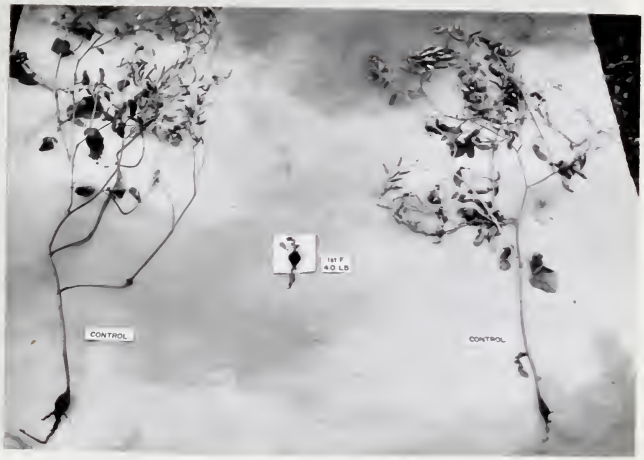

Figure 28. Very meager growth followed the early 4.0 lb./A application of MH-40 to the foliage at the pre-market size. stage.

Figure 29. Approximately one month after 2.0 lb./A early foliage MH-40 treatment there was a resumption of a small amount of abnormal and spindly growth from the hypocotyl as shown.

Figure 30. Inhibition of growth was less pronounced following a 10.0 lb./A early root application of MH-40, but terminal growth was arrested at the point indicated by the arrows. Lateral growth resumed later.

Figure 31. Pronounced reduction in seed pod set (Figure 41), reduction of growth, and earlier maturity followed late foliage 4.0 lb./A application of MH-40 at the stage of full bloom.

Figure 32. The 10 lb./A late root treatment of MH-40 inhibited terminal growth. Later vigorous lateral branches developed. Seed pod set was significantly reduced. (See Figure 41).

2. Quantitative Observations

(a) Vegetative Development

Weight of Plant Tops. The mean weights of the plant tops harvested at market size nine days after treatment, are shown graphically in Figure 33 based upon the data given in Appendix I and II.

In the Greenhouse Trial the effect of the 0.01%/½ hour seed treatment is the only one which resulted in a significant increase in weight, at P equal to .01. The 0.02%/2 hours seed and the 0.4 and 2.0 pounds per acre early foliage treatments and all root treatments resulted in no significant differences from the corresponding control plots for each trial. In the early foliage treatments there was a significant decrease in weight from the 0.1 and 1.0 pound per acre rates and a highly significant decrease from the 4.0 pound per acre application of MH-40.

In the Field Trail early foliage treatments the decrease in top weight was significant for the 0.5 pound rate and highly significant for the 4.0 and 8.0 pounds per acre rates.

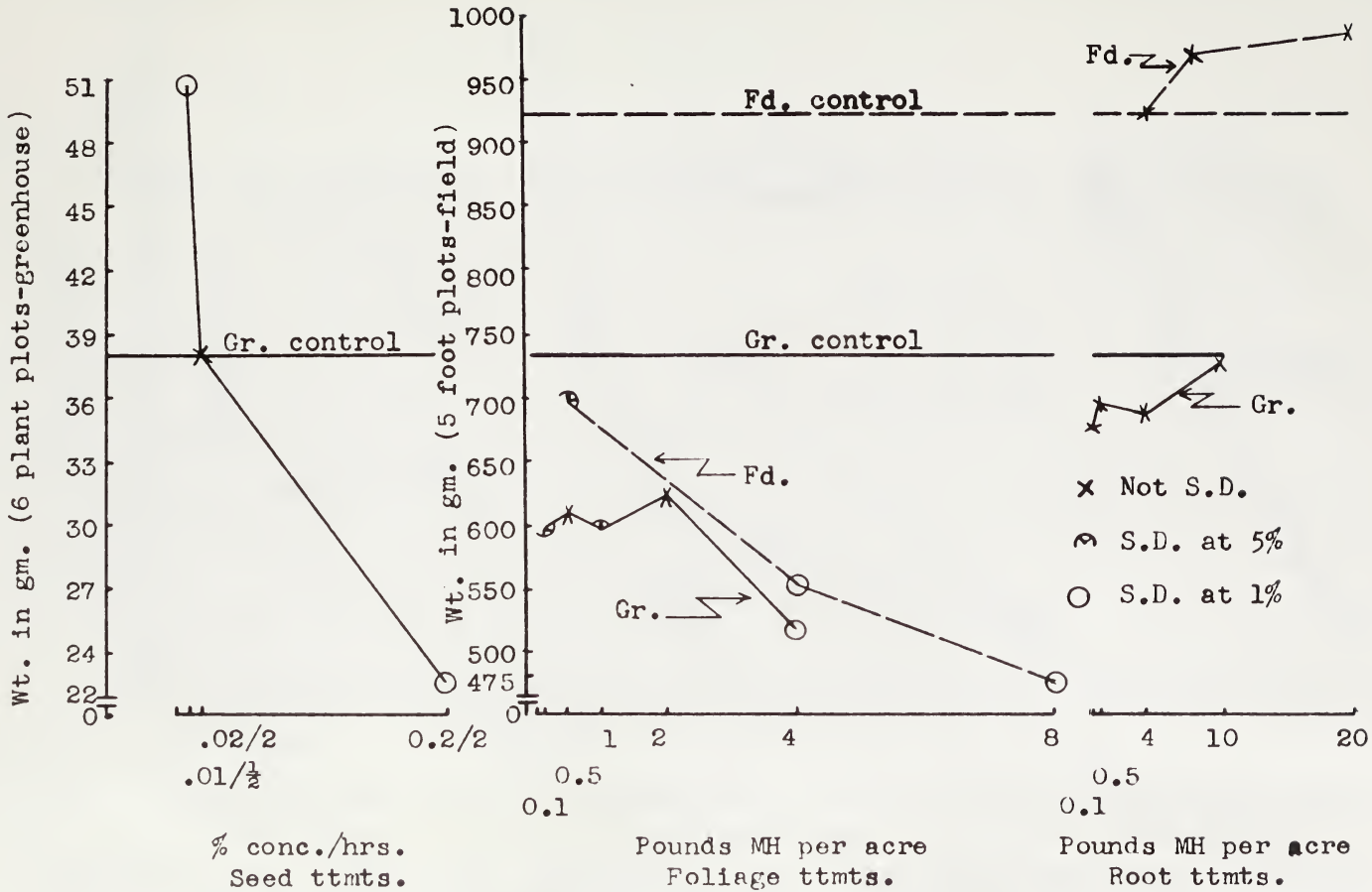

Figure 33. Mean weight of top growth from radish plots harvested at market size from greenhouse and field trials. Refer to Appendix I and II.

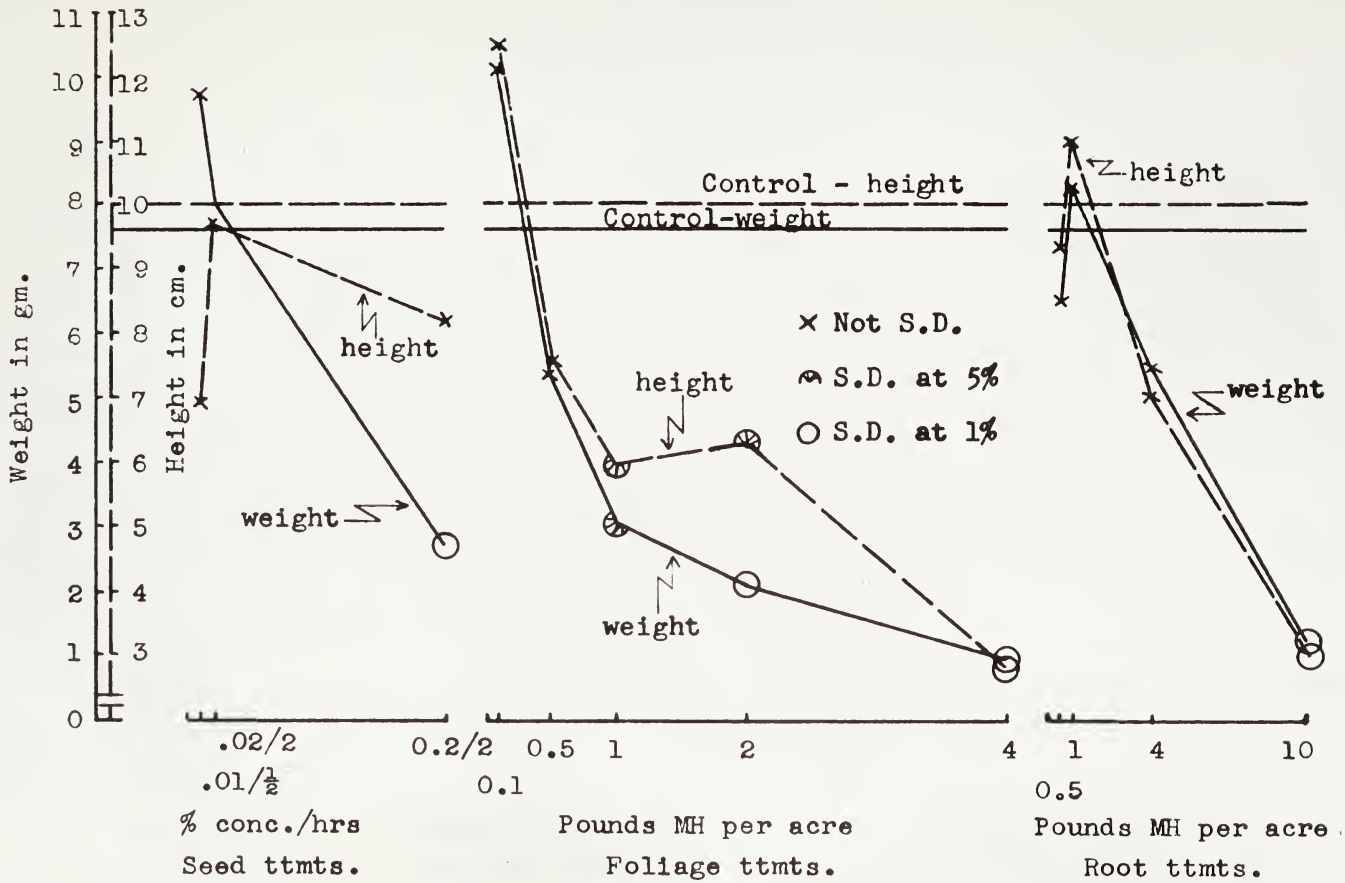

Figure 34. Mean weight in gm. and height in cm. of new top growth from hypocotyls in cool storage for five weeks. Refer to Appendix IV and V.

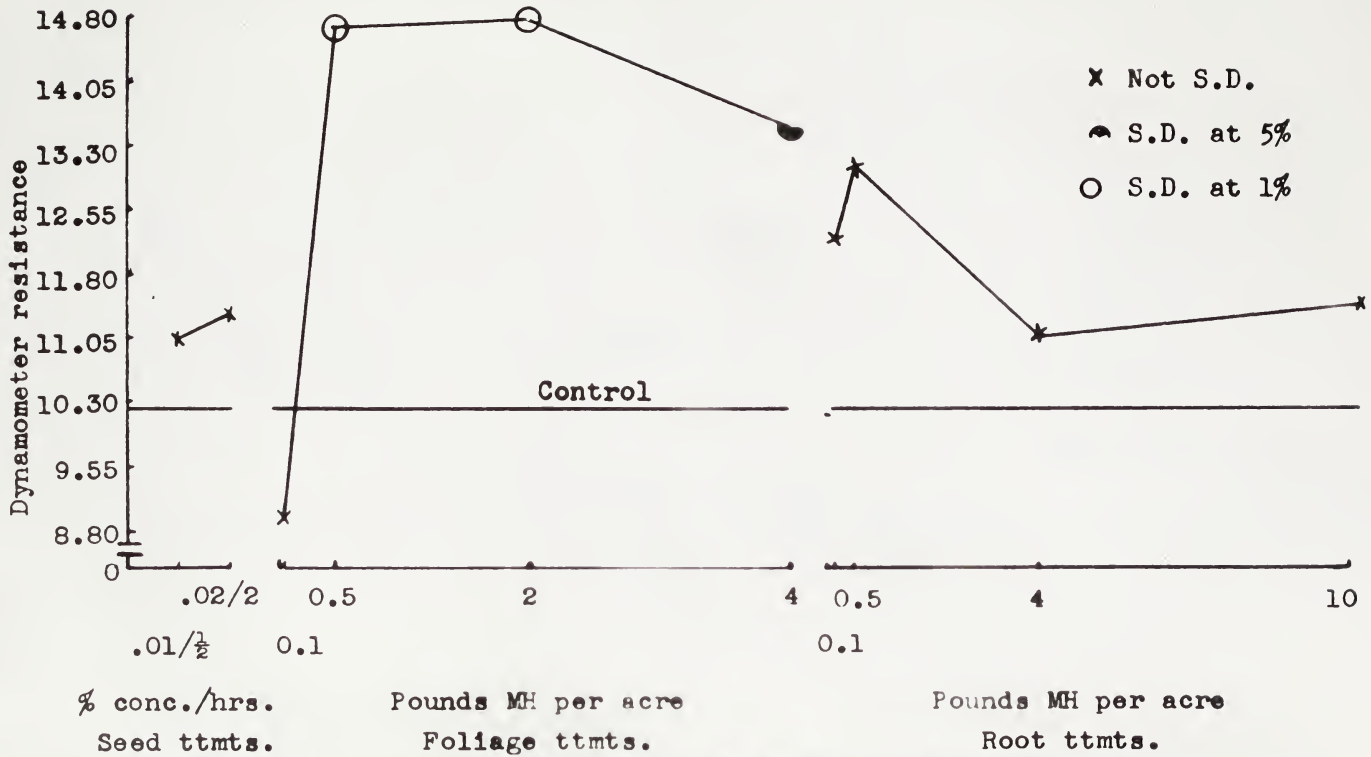

Figure 35. Mean resistance to puncture of radish hypocotyl as measured in lb. pressure per unit area of dynamometer plunger head following six weeks in cool storage. Refer to Appendix VI.

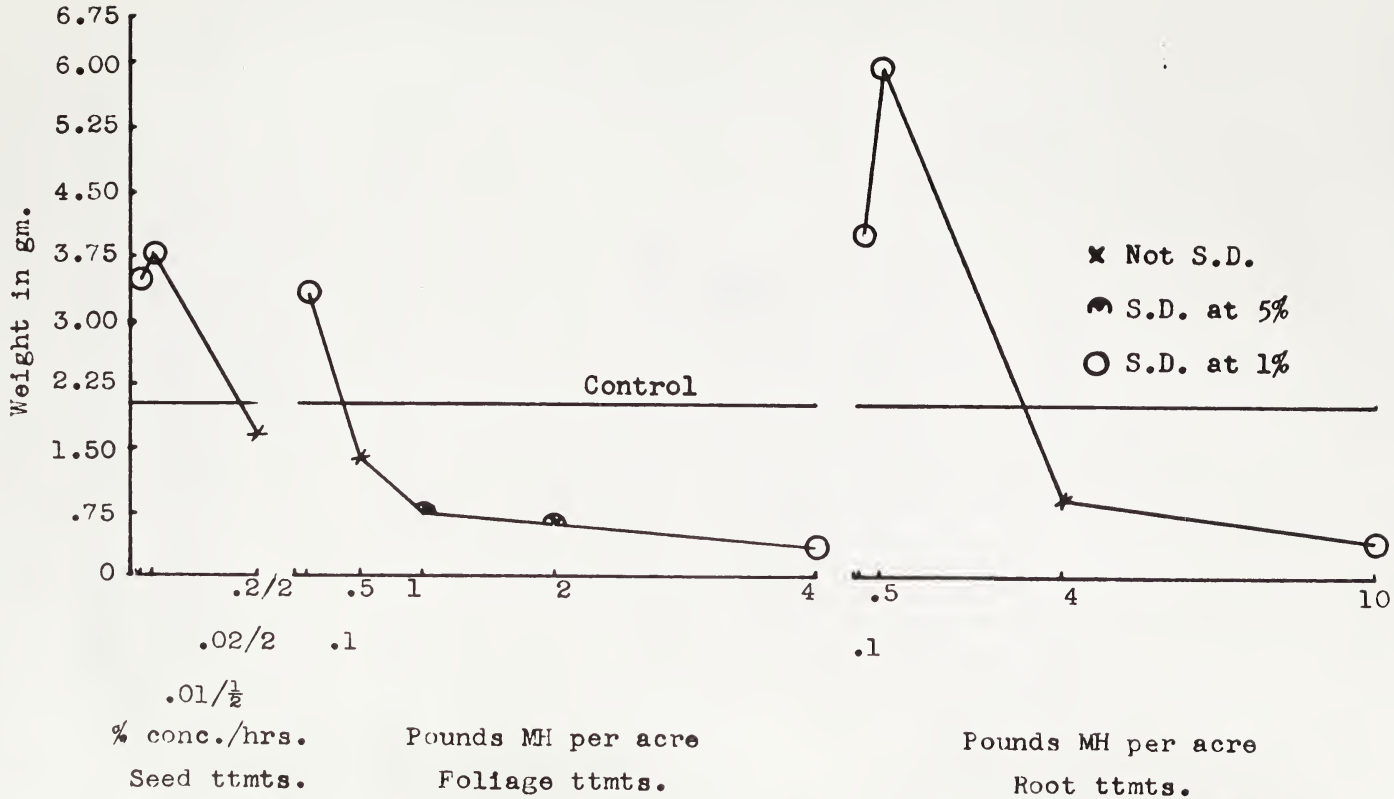

Figure 36. Mean weight of individual roots plus firmly adhering vermiculite as a measure of the renewed root growth from cold stored hypocotyls. Refer to Appendix VII and Figure 7.

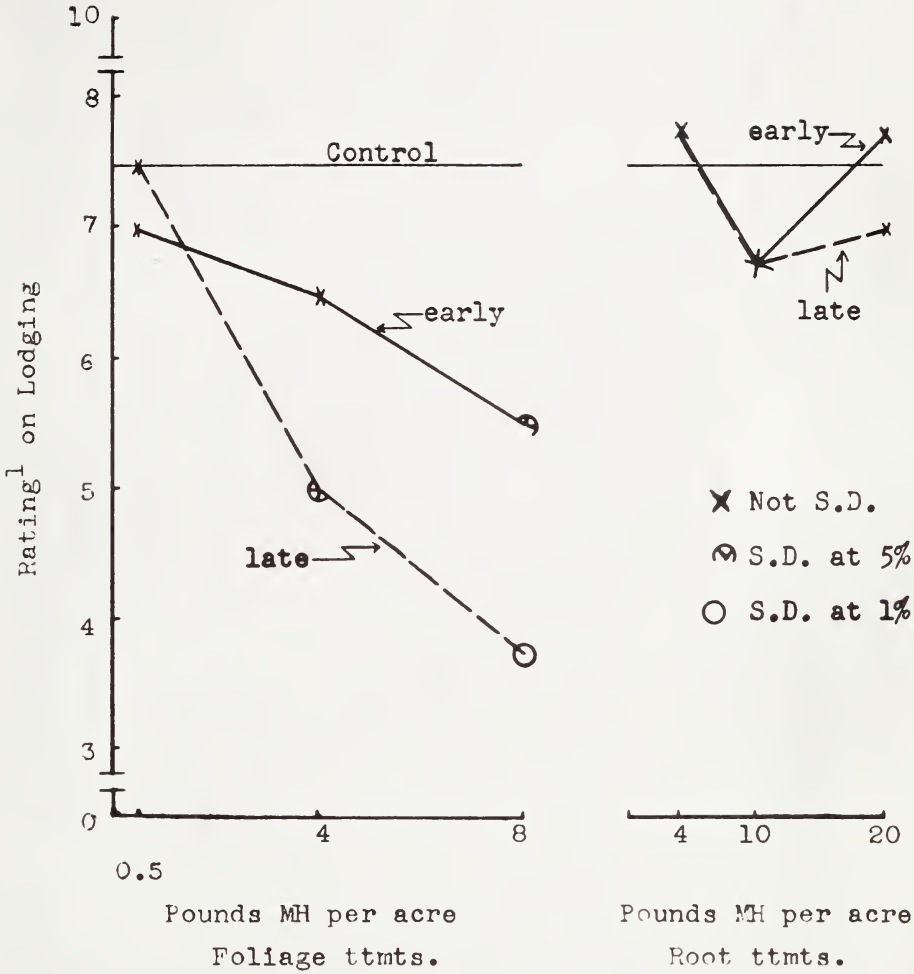

Figure 37. Mean visual rating[1] on degree of lodging thirteen weeks after sowing. Field Trial. Refer to Appendix X and figure 11.

[1] Rating; 1=minimum lodging, 10=maximum lodging.

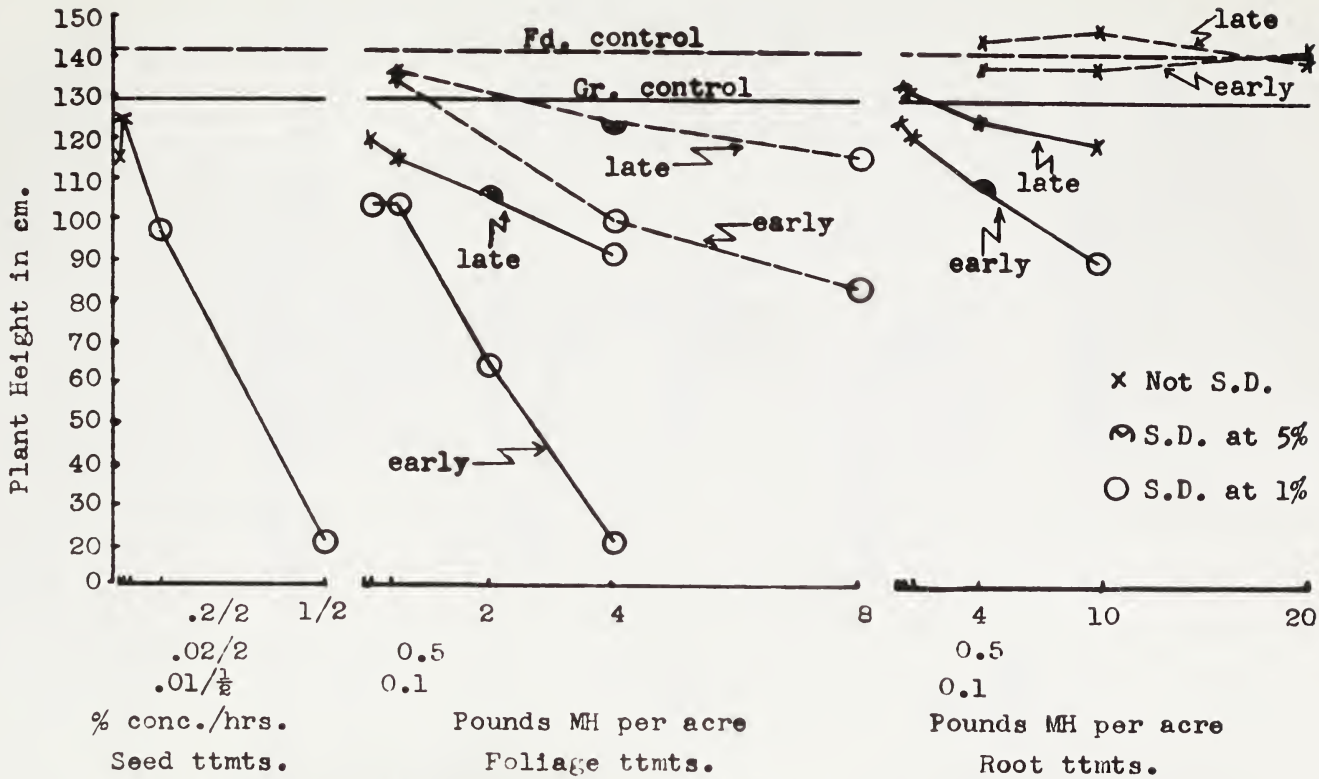

Figure 38. Mean plant height of plots at the end of growing season. Refer to Appendix XI and XII.

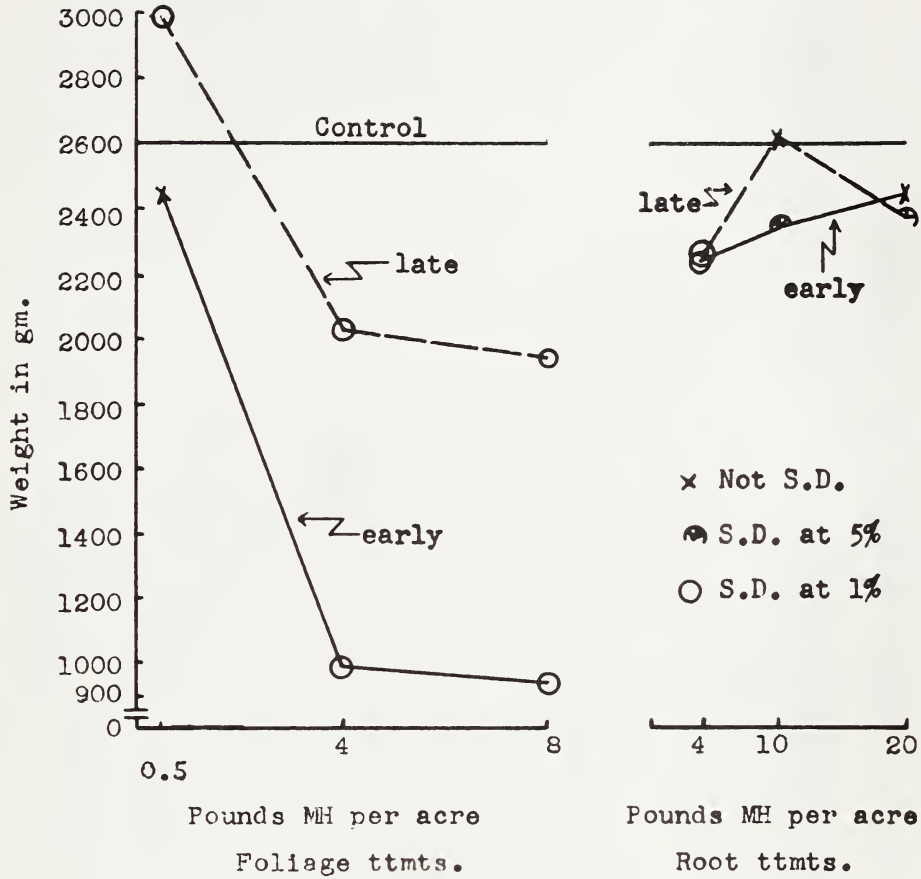

Figure 39. Mean air dry weight of whole plants harvested fifteen weeks after sowing. Field Trial. Refer to Appendix XIV.

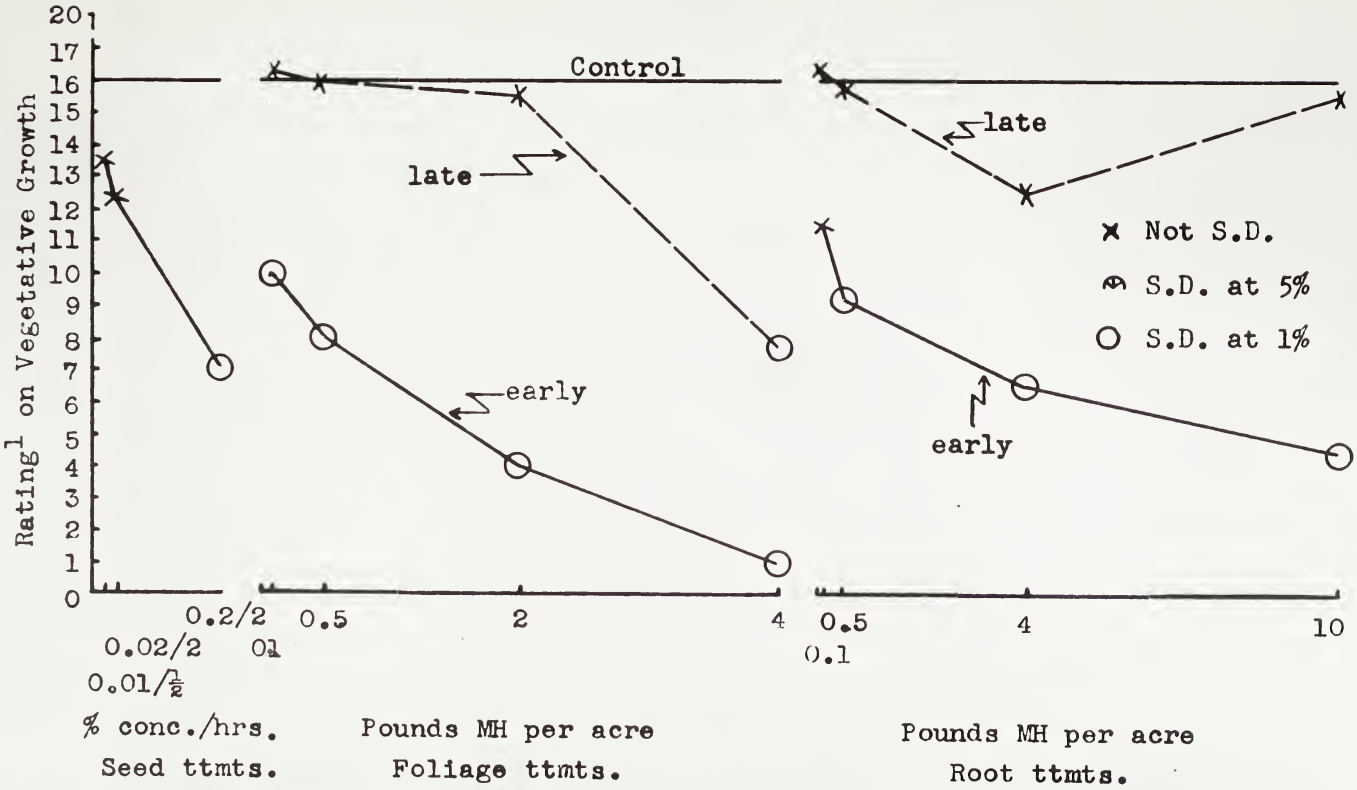

Figure 40. Visual rating[1] on amount of vegetative growth made fifteen weeks after sowing. Greenhouse Trial. Refer to Appendix XV and figures 24 to 32.

[1] Rating on amount of growth; 1 = least, 20 = greatest.

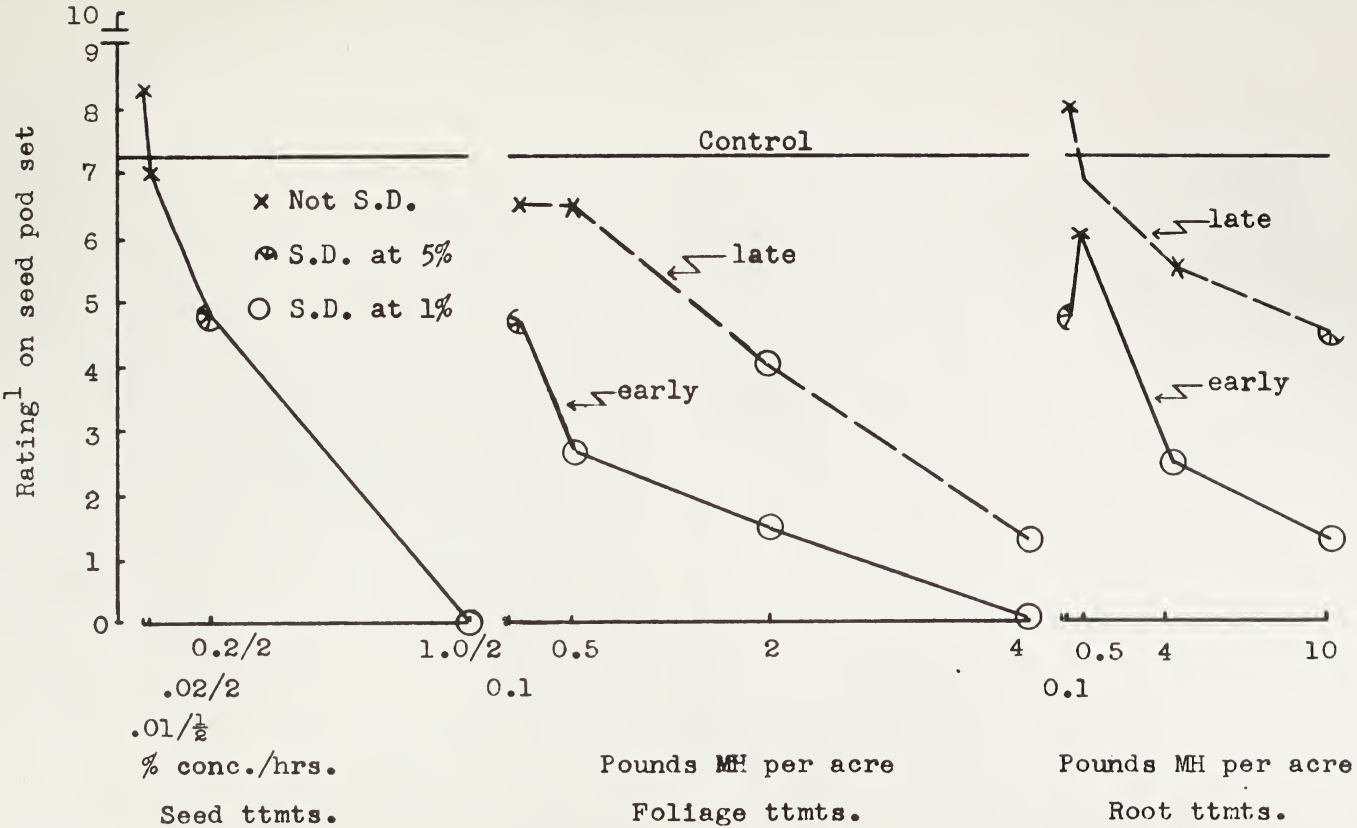

Figure 41. Mean visual rating[1] on amount of seed pod set fifteen weeks after sowing. Greenhouse Trial. Refer to Appendix XVI and to Figures 24 to 32.

[1] Rating of seed pod set; 1 = poorest, 10 = best.

Hypocotyl Weight. For the Greenhouse Trial the data on hypocotyl weight are tabulated in Appendix III. Only the 0.20%/2 hours seed treatment resulted in a highly significant decrease in weight. Results from the Field Trial revealed no significant differences between treatments in the weight of hypocotyls harvested at market size.

Shoot Regrowth. The weight and height of the new growth of shoots from cool stored hypocotyls from treatments of the Greenhouse Trial are shown graphically in Figure 34 based upon the data given in Appendix III and IV. All the significant differences were lower than the control.

The weight of shoots from the 0.2%/2 hour seed, the 2 and 4 pounds early foliage and the 10 pounds per acre early root treatments was less than the shoot weight of the controls at P equal to .01. The weight of shoots from the 1.0 pound per acre early foliage treatment was below that of the control but was significantly so only at the 5 per cent level. In the 1.0%/2 hours seed treatment there were not enough hypocotyls at the time of storage to be included in this test.

The height of new shoot growth was collected for the purpose of noting any great variations in

Concentric height. For the concentrics (Set 3) both in dynamic height and considered in absolute alt. Only the 0.20\2 mm/mm peak treatment result in a highly significant decrease in height. Neither the field data nor reveals no significant difference among column treatments in the amount of dynamic harvested at several sites.

Floral density. The height and height of the two types of shoots (floral stems) (vegetative from consideration of the Dendrograms data) the shoot consistency in figure 34 based upon the data given in Appendix 1c and 1f. All the significant differences were lower than the control.

The height of shoots from the 0.20\2 mm/mm and the 0 and 4 months early fertiles and the 10 month per mm early root treatments was less than the control 1c\2 of the concrete at 2 month in . The height of shoots from the 1.0 month and early fertile treatment was below that of the control but the fertility of only of the 2 mm mm in the 1.0\2 month root treatment lower than the control irrespective of the time of storage to be placed in this test.

The height of the shoot growth was reflected in the number of nodes and shoot internodes in

the type of growth made. Figure 34 shows that the height of regrowth follows quite closely the same trend or pattern as that for the weight with the exception of the 0.01%/2 hours seed treatment. At the latter rate the type of growth was found to be comprised of a greater number of shorter vegetative shoots than those produced in the other treatments.

Root Regrowth. The weight of root regrowth obtained from hypocotyls placed in cool storage at the market size for six weeks included also the vermiculite firmly adhering to individual roots that were cut off at the base of the hypocotyl. Marked visual differences in the amount of root regrowth are shown in Figure 7. Quantitative differences are shown graphically in Figure 36 based upon the original weight data given in Appendix VII.

Figure 36 indicates that in the following treatments there were increases in the root regrowth at the 1 per cent level of significance:

1. The 0.01%/½ hour and 0.02%/2 hours seed treatments.
2. The 0.5 pound per acre early foliage treatment.
3. The 0.1 and 0.5 pound per acre early root treatments.

In the 4 pounds per acre early foliage and the 10 pounds per acre early root treatments highly significant reductions in root growth were noted. The weights for the 1.0 and 2.0 pounds early foliage treatments were significantly below the control for a P value of .05.

Lodging of Stems. Typical lodging of the plant tops in the field for the 8 pounds per acre early foliage treatment is shown in Figure 11. A visual score was made on the amount of lodging of plant tops in the Field Trial 13 weeks after sowing. These results are shown graphically in Figure 37 and in data form in Appendix X. Only the 8 pounds per acre late foliage treatment showed a highly significant reduction in the amount of lodging, and only the 8 pounds early foliage and 4 pounds late foliage treatments showed a reduction significant at the 5 per cent level.

Plant Height. The mean plant height in centimeters, taken near the end of the growing season or 13 weeks after sowing in the Greenhouse Trial and 12 weeks after sowing in the Field Trial, is recorded in Appendix XI and XII and is illustrated graphically in Figure 38.

Figure 38 shows that treatments of MH-40 result in a definite trend towards a reduction in plant height with increasing rates of application. This reduction was most marked in the seed treatments and the early foliage treatments. Furthermore the reduction in plant height with increasing rates of application of MH was generally more pronounced in the Greenhouse Trial than in the Field Trial. This was indicated by the difference in the slope of the curves for the two trials as shown in Figure 38.

In the Field Trial, Figure 38 indicates that neither the 0.5 pound early and late foliage treatments nor the root treatments resulted in significant reductions in plant height. However significant reductions resulted from the use of the 4 pounds late foliage treatment at the 5 per cent level and also from the 8 pounds late and 4 and 8 pounds early foliage treatments at the 1 per cent level.

In the Greenhouse Trial the following treatments caused highly significant reductions in plant height:

1. The 0.2% and 1.0%/2 hours seed treatments.
2. The 0.1, 0.5, 2.0 and 4.0 pounds per acre early foliage treatments.
3. The 4 pounds late foliage treatment.

4. The 10 pounds early root treatment.

Other treatments resulted in reductions in plant height which were significant at the 5 per cent level of probability. These are listed below:

1. The 2.0 pounds early foliage treatment.
2. The 4 pounds early root treatment.

Final Plant Weight. Fresh and air dry weights of entire plants were obtained 15 weeks after sowing in the Field Trial. Appendix XIII contains the data on the fresh weight of whole plants harvested from half the usual plot and Table 3 presents the yields of the treatments found significant. Table 3 shows a highly significant reduction in the fresh weight of the 4 and 8 pounds early foliage treatments. The least significant values obtained after analyzing were very large compared with corresponding values obtained for the dry weights. The result is that the fresh weight value based upon half plots is a much less refined measure of plant growth than the air dry weights.

The data on the air dry weight are contained in Appendix XIV and given graphically in Figure 39. Two unexpected results are shown in Figure 39; first, a highly significant increase in weight for the 0.5 pound late foliage treatment; secondly, in the late root treatment there was no significant reduction

in weight at the 10 pounds per acre rate while at the 4 and 20 pounds rates there were significant reductions. In the early root treatments there were significant reductions at the 4 and 10 pounds rates but none at the 20 pounds rate of application. At 4 and 8 pounds per acre in both the early and late foliage applications there were highly significant reductions in total plant weight.

Table 3. Significance of results. Mean fresh weight of total plants harvested from half plots 15 weeks after sowing. Field Trial.

Rate in lb. per acre applied as early foliage treatments.	Mean weight in grams.
0.0 (Control)	7046
4.0	3309**
8.0	2793**

L.S.D. P (.05) = 2514 grams

S.D. P (.01) = 3368 grams

Final Vegetative Growth. In the Greenhouse Trial the amount of vegetative growth present 15 weeks after sowing was estimated by a visual rating based on a range of 1 to 20, where 1 is used for the least growth and 20 for the greatest amount of growth. The data are given in Appendix

XV and shown graphically in Figure 40. In this trial, all treatments which showed highly significant reductions, compared with the control plot data, are listed as follows:

1. The 0.2%/2 hours seed treatment.
2. The 0.1, 0.5, 2.0 and 4.0 pounds per acre early foliage treatments.
3. The 4.0 pounds per acre late foliage treatment.
4. The 0.5, 4 and 10 pounds per acre early root treatments.

In the 1.0%/2 hours seed treatment there were not enough plants remaining at the end of the season upon which to base an accurate score on the amount of vegetative growth. However the amount of growth was much less than that for the 0.2%/2 hours seed treatment.

(b) Reproductive Development

Date of Flowering. A striking delay in the reproductive development followed the early foliage applications of MH-40 at the two heavier rates in both Greenhouse and Field Trials. This is shown by Table 4, which contains the significant part of complete data collected from the Field Trial and this delay is represented in Appendix VIII as the mean number of days from emergence to first bloom. Table 5, obtained from Appendix IX, con-

tains the significant results for the mean number of days from emergence to date of full bloom. A highly significant delay in the reproductive development resulting from the early foliage treatments of 4.0 and 8.0 pounds per acre is shown in both Table 4 and Table 5.

Table 4. Significance of Results. Mean Number of Days from Plant Emergence to First Bloom. Field Trial.

Rate in lb. per acre applied as early foliage treatments.	Mean number of days.
0.0 (Control)	43.8
4.0	70.3**
8.0	70.3**

L.S.D. P (.05) = ± 2.9 days
S.D. P (.01) = ± 3.9 days

Table 5. Significance of Results. Mean Number of Days From Emergence to Full Bloom. Field Trial.

Rate in lb. per acre applied as early foliage treatments.	Mean Number of days.
0.0 (Control)	57.5
4.0	78.5**
8.0	81.0**

L.S.D. P (.05) = ± 2.64 days
S.D. P (.01) = ± 3.67 days

Seed Pod Set. Data from Appendix XVI, graphed in Figure 41, show the results obtained from a visual rating on the amount of seed pod set from treatments in the Greenhouse Trial. At a P value of .05 the following treatments resulted in significant reductions below the controls:

1. The 0.2%/2 hours seed soaking treatment.
2. The 0.1 pound early foliage treatment.
3. The 0.1 pound early root treatment.
4. The 10 pounds late root treatment.

The following treatments resulted in highly significant reductions below the control:

1. The 1.0%/2 hours seed soaking treatment.
2. The 0.5, 2.0 and 4.0 pounds early foliage treatments.
3. The 2.0 and 4.0 pounds late foliage treatments.
4. The 4.0 and 10.0 pounds early root treatments.

The above results show that the earlier treatment is applied in the life cycle of the plant the greater is the reduction in seed pod set. Foliage sprays produce greater reductions than root applications.

Effects on Hypocotyl Quality

The effects of MH-40 on the hypocotyl quality of radish were measured as; (1) the firmness of the hypocotyl tissue after a period of storage and (2) the per cent content of total soluble solids.

1. Firmness of Hypocotyl Tissue

It was assumed that ease of or resistance to puncture by a dynamometer plunger provided a measure of tissue breakdown, and that in the case of healthy hypocotyls this breakdown was a result of respiration activity during the period of storage and root and shoot regrowth. Data collected on this statistic after six weeks storage are shown in Figure 35 for the Greenhouse Trial. The graph, based upon the data given in Appendix VI, shows a highly significant increase in the resistance to puncture of the hypocotyl for the 0.5 and 2.0 pounds per acre early foliage treatments and a significant increase for the 4 pounds early foliage treatment. Radish plants given an early foliage application at 4.0 pounds per acre showed no significant difference in tissue firmness following a cold storage period of 18 days. Following 54 days storage however there was a highly significant increase in the hypocotyl resistance to puncture. The average dynamometer reading

for sprayed and control treatments following 54 days of cool storage at 4° C is given in Table 6, and these figures show an average increase of 0.79 dynamometer units per hypocotyl. This represents an increase of 4.3 per cent over the controls.

Table 6. Average resistance to puncture of hypocotyls as measured by dynamometer determinations for the 4.0 lb. MH per acre foliage and control treatments following 54 days in cool storage at 4° C.

Sprayed	Control
19.27	18.48

t value = 5.34**

** Exceeds the 1 per cent level of significance

2. Total Soluble Solids Content of Hypocotyls

A Bausch and Lomb hand refractometer (0 - 60% range) was used to determine soluble solids from expressed sap of radish hypocotyls. Readings from this refractometer were taken at the market size of the hypocotyl or seven days after foliage treatment at 4 pounds per acre. Data are given in Table 7. The results show a highly significant increase of 1.35 per cent total soluble solids (an increase of 24.7 per cent over the control), or on the basis of relative water content this may be a corresponding decrease in per cent moisture of hypocotyls. Similar measurements taken following a period of 18 days

in cool storage showed no significant differences.

Table 7. Average per cent soluble solids content of hypocotyls (relative moisture content unknown) as measured by a refractometer seven days following foliage spray treatments of 4.0 pounds MH per acre. Quality Trial.

Sprayed	Control
6.82	5.47

t value = 5.68**

** Exceeds the 1 per cent level of significance

Effects of Treatment upon the T_1 Generation

Data collected one month following sowing on the germination ability of the T_1 generation planted in loam soil in greenhouse flats is given in Appendix XVII. The emergence count, taken one month after sowing, shows a highly significant reduction in the per cent of emergence of the seed collected from plants receiving late foliage application of MH at 4.0 pounds per acre, and a significant reduction for the 4.0 pounds late root treatment of MH. Seed from the 8 pounds late foliage application were not viable but consisted of shrunken seed parts and a shrivelled brown seed coat. In the 4 pounds late foliage treatment there were approximately 80 per cent of the seeds which were in the same condition.

Three weeks after the seedlings had emerged a root rot became established, largely due to very damp conditions.

in each lesion shown no significant difference.

Table 7. Average per week bulbous bolter number in normally (healthy) relative control (control) is measured by a relativeness based upon the ratio of per week. Quality (qual).

Treated	Control
.05	2.07

t value = 3.0***

** Exceeds the 1 per cent level of significance

Effect of treatment upon the Quality

The quality and count relationship varies as the treatment (qual) of the 5 treatment climate in terms of a connection with is given in Kennedy Avil. The treatment count, again one only, after bolter, shows a slight significant reduction in the use test of treatment. If the best quality, the lower receiving late voltage application of 10 to 5.1 ounces per week, and a significant reduction for the 1.0 ounces late foot treatment of 5.1. Good (qual) for a double late voltage application was not slight in translated to strongest case parts and a moderate brown area qual. In the 4 double late voltage treatment there was correlation 7% per cent in the black which was in the same condition.

There were also the results had received a poor qual

This disease caused much girdling of the stems which in turn caused unnatural formative effects. For that reason no attempt was made to determine whether MH applied to the parent plants produced formative effects upon the T_1 generation, but no gross formative effects due to treatment were evident in a population of approximately 450 plants.

DISCUSSION OF RESULTS AND CONCLUSIONS

1. Physiological Effects of Treatment

Maleic hydrazide primarily exerts its physiological influence on the vegetative and reproductive processes of the radish plant through arresting the growth of all meristems present at any stage of active growth shortly after direct or indirect application of the chemical. This explains the observation that with few exceptions MH reduced the weight of hypocotyls, plant tops, the regrowth of rootlets and shoots from hypocotyls kept in cool storage, and reduced the amount of seed pod set.

The apparent stimulating effect of MH at the lighter rates of treatments, shown in Figure 36, for the regrowth of roots from hypocotyls may be explained on the basis of findings of Klein and Leopold as reported by Zukel (35). That is, stimulation is affected only through the MH acting as an auxin competitor in the presence of true

growth regulators. Then MH may stimulate growth through the removal of inhibition due to the presence of over-abundant auxin. The observation that no significant increases in shoot regrowth (Figure 34) at the same rates which induced significant increases in the root regrowth (Figure 36) may be explained on the basis of the well known principle that more auxin is required to inhibit growth in shoots than in roots. Therefore less MH would be required to remove the inhibition in the growth of roots than for shoots or, as a corollary, less MH may induce an apparent stimulation in the growth of the former but not in the latter.

The one significant increase in yield noted following a late foliage application of 0.5 pound per acre is undoubtedly due to the chance position of this treatment in the field plan. In all four replicates the position of this treatment occurred to one end near a hedge which imparted a marked beneficial effect in growth. This was the only treatment which had more than two out of four replicated plots occurring near the hedge.

The results showing a reduction in the amount of lodging following heavy foliage treatments of MH, (Figure 37) are interpreted simply on the basis of external observations. Lodging in comparison to the controls was reduced following heavy foliage sprays at the pre-harvest size stage and at the full bloom size

stage because further shoot growth was so meager and short that the plant tops were much lighter in weight than the controls.

It was noted that the duration of inhibition or severity of effect was increasedif MH was applied (1) to plants early in their life cycle or (2) when plants were rapidly growing. These are results which may be expected since MH acts through the physiological processes. The effect would probably be greatest when the physiological activity is the most rapid. Recovery from such inhibition or injury would be more difficult for very young plants than for older and better established plants. This was found to be the case following treatments made at the stages of pre-harvest and pre-emergence compared to the full bloom stage.

The response from the root method of application was less severe and direct than the response from the foliage method of application. This result may be expected to follow from the more indirect path of absorption necessary if the MH must pass through the soil before being absorbed by the plant roots rather than being absorbed through the leaves.

The mechanism of the effect of MH in reducing the viability of the T_1 generation seed is a similar problem to that involved following direct applic-

ation to plants. Presumably, the reduction in seed viability would be responsible for some reduction or retardation in eventual plant growth. In any case it could represent a serious loss to seed producers or to gardeners utilizing seed from treated plants.

The results support the conclusion that MH acts as a temporary growth inhibitor through arresting cell division in terminal meristems. One explanation for this effect is that MH acts in opposition to the natural plant hormones. Other actions may also be involved and until the exact mechanism of the action of MH is known no more definite conclusion can be drawn.

Decreased physiological activity is the most logical explanation for the significant increases in resistance to puncture of the hypocotyl following pre-harvest foliar sprays as reported for two separate trials. This is supported by the results illustrated in Figures 34 and 36 showing reduced shoot and root regrowth and the conclusion of others that MH treatment causes a reduction in the rate of respiration. The possibility is not excluded that other changes, such as more rapid loss of water and a tougher outer tissue, also contributed to the results obtained. However since there was no visible basis for such supposition it is concluded that the result can be attributed to decreased

respiration and regrowth which would result in less rapid morphological breakdown of the hypocotyl tissue.

Following pre-harvest foliage sprays there was a significant increase in the per cent of total soluble solids of the hypocotyls, measured on the basis of extracted juice available. This increase may have been due to (1) a decrease in the amount of water present, (2) an increase in the manufacture of carbohydrates that were translocated to the hypocotyls, (3) a decrease in the rate of carbohydrate removal from the hypocotyls either through (a) a decrease in the rate of respiration, or (b) interference in the transport of carbohydrates away from the hypocotyls. The first of these suggestions appears to be the most likely with the other possibilities somewhat less likely to account for the increase noted. Such a conclusion is based upon the observation that 18 days later there was no significant difference in total soluble solids content. If a true difference in carbohydrates were present then this difference should only have been lost in storage due to increased respiration or growth activity. However the other results obtained show that growth activity was less (Figures 34 and 36) and strongly suggest , in agreement with other reports (30) (35), that respiration was reduced following preharvest foliage treatments (See Figure 35). Further-

more if MH treatment hinders the conduction of carbohydrates, as Greulach (15) has reported, or causes injury of the vascular tissue, as other workers have suggested (31) (36), then it is hard to explain how more total soluble solids would be translocated to the hypocotyls. On the other hand if MH treatment is followed by an increase in the transpiration of water (25) (32) then the apparent increase in the percentage of total soluble solids might be explained as largely or entirely due to a decrease in the moisture content of the hypocotyl. Such a conclusion need not cast doubt on other reports of increased carbohydrate content in root crops following treatment, but does suggest that all measurements of carbohydrate content should be made on the basis of known dry weight or a known amount of moisture.

2. Anatomical Effects of Treatment

Only two detailed accounts (23) (31) describing the anatomical effect of MH has been obtained to date, and these offer no explanation for the observations noted.

Struckmeyer (31) has reported an increase in leaf thickness due to MH treatment which is attributed to a looser arrangement of the cells and partly to an increase in the size of the cells rather than increased cell numbers. McIlrath (23) attrubutes thickening in cotton leaves following treatment entirely to cell

enlargement. The 65 per cent increase in leaf thickness for treated radish leaves over that of the control is attributed by the author to be due to the differentiation of an extra irregular row of palisade cells and also to a looser cell arrangement. Accurate counts were not made from the ten slides prepared to determine if there was any increase in the number of rows of cells. The similarity existing between the structure noted in the treated and non treated leaves to that observed in many species for sun and shade leaves respectively appears to be sufficient to warrant further comparisons of this type. To date no report has been found stating that MH treatment has resulted in an increase in the number of rows of palisade cells.

The observation that palisade cells of treated leaves were largely in a state of collapse as compared to untreated leaves is directly in line with Struckmeyer's results (31) in the Croft Easter Lily. She attributes the difference noted to a disintegration of the chloroplasts in both palisade and spongy parenchyma cells. In the radish leaf examination was not detailed enough to give the reason for the collapsed state of palisade cells in treated leaves.

SUMMARY

1. Experiments were conducted using the common radish as the plant material with the objective of learning more about the effects of maleic hydrazide upon the growth and quality of root crops and upon general plant development.

2. Maleic hydrazide (Naugatuck MH-40) was applied in quantities expressed as active ingredient by two methods for each of three stages in the life cycle of the radish as follows:

   (a) Pre-emergence stage

      (i) To the soil at 10, 20 and 30 pounds MH per acre two days after sowing.

      (ii) By soaking seed in treatments at 1.0/2, 0.2/2, 0.02/2 and 0.01/½ per cent concentration per hours time.

   (b) Pre-market size stage

      (i) In foliage sprays at 0.1, 0.5, 1.0, 2.0,4.0 and 8.0 pounds per acre.

      (ii) To the roots through the soil at 0.1, 0.5, 4.0, 10 and 20 pounds per acre.

   (c) Full bloom stage

      (i) In foliage sprays at 0.1, 0.5, 2.0, 4.0 and 8.0 pounds per acre.

      (ii) To the roots through the soil at 0.1, 0.5, 4.0, 10 and 20 pounds per acre.

3. The sensitivity of the plants to the effects of MH treatment varied in the following manner:
   (a) Directly with the rate of application.
   (b) Directly with the rate of growth.
   (c) Inversely with the age of the vegetative or reproductive stages.
   (d) More directly and severely for the foliage method than for the root method of application.
4. MH applied at medium or heavy rates by root or foliage treatments at all three stages was found to result in significant reductions in the weight of plant tops, hypocotyls, and in shoot and rootlet regrowth from hypocotyls subjected to a cool storage period. This was due to inhibition in the growth of the terminal meristems.
5. Low rates of MH treatment induced significant increases in the amount of rootlet regrowth from hypocotyls in storage but not in the regrowth of shoots.
6. Foliage sprays of MH at 4 pounds per acre made at the pre-harvest size stage resulted in:
   (a) An apparent significant increase in the per cent of total soluble solids per hypocotyl which was attributed to a decrease in the moisture content.
   (b) A significant decrease in the rate of softening of the hypocotyl tissue in storage as measured by resistance to puncture.

7. MH sprayed to the foliage at 4 and 8 pounds per acre at the full bloom stage resulted in:
   (a) Abnormalities, sterility and abscission of floral parts if seed formation was not already begun prior to treatment.
   (b) Increased seed pod diameter containing seed shrunken in varying degrees if seed formation had commenced prior to treatment.
   (c) Great reductions in the viability of the seed formed.
8. Foliage sprays of MH induced anatomical changes in the leaf, which are noted below:
   (a) The formation of an extra and irregular row of palisade cells formed immediately beneath the normal two rows.
   (b) An increase in leaf thickness of more than 50 per cent.
9. It is concluded that MH acts in the following ways:
   (a) As a temporary growth inhibitor when applied in sufficient amounts. It promptly arrests the cell division in the terminal meristem possibly through its action in opposition to the natural plant hormones.
   (b) Regrowth of plant parts is reduced, and thus the rate of morphological breakdown in storage is delayed.

10. Comments which may be developed from this study are:

(a) MH may be useful for increasing the storage life of certain plant products, but its use on edible food plants cannot be recommended until more is known about the mammalian toxicity of this chemical.

(b) For optimum results it will be important to know the best time and rate for application of MH to plants.

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[illegible]

APPENDIX I

A. Mean weight of top growth from radish harvested at market size. Greenhouse Trial. (24 plants per plot).

Seed treatments		Foliage treatments		Root treatments	
		Early		Early	
Rate % conc. hours	Weight in gm.	Rate lb. per acre	Weight in gm.	Rate lb. per acre	Weight in gm.
0.01/½	49.5**	0.1	29.8*	0.1	34.5
0.02/2	37.9	0.5	30.6	0.5	35.5
0.20/2	22.7**	1.0	29.8*	4.0	35.0
		2.0	31.3	10.0	37.3
		4.0	25.1**		

Control - seed sown dry.....29.9**
Control - seed soaked 2 hours in water.....37.9

Significantly different from the control (seed soaked in water)
* at the 5% level
** at the 1% level

B. Analysis of Variance - Weight of Plant Tops, Market Size. Greenhouse Trial.

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	55	3459.3		
Replicates	3	145.9	48.64	1.73
Treatments	13	2224.3	171.10	6.07**
Error	39	1099.1	28.18	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 7.6 gm.
P. (.01) = ± 10.2 gm.

APPENDIX II

A. Mean weight of top growth from radish harvested at market size. Field Trial. (Ten foot plots).

Foliage treatments		Root treatments	
	Early		Early
Rate lb. per acre	Weight in gm.	Rate lb. per acre	Weight in gm.
0.5	696.0*	4	921.3
4.0	552.8**	10	965.8
8.0	475.0**	20	983.3

Control.....922.3

Significantly different from the control
* at the 5% level
** at the 1% level

B. Analysis of Variance - Weight of Plant Tops at Market Size. Field Trial.

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	51	2551483		
Replicates	3	73252	24417	1.48
Treatments	12	1883398	156950	9.50**
Error	36	594833	16523	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 184.3 gm.
P. (.01) = ± 247.2 gm.

APPENDIX III

A. Mean weight of radish hypocotyls harvested at market size. Greenhouse Trial. (24 plants per plot).

Seed treatments		Foliage treatments		Root treatments	
		Early		Early	
Rate % conc. hours	Weight in gm.	Rate lb. per acre	Weight in gm.	Rate lb. per acre	Weight in gm.
0.01/½	91.4	0.1	67.9	0.1	73.0
0.02/2	71.2	0.5	75.8	0.5	83.7
0.20/2	36.0**	1.0	83.5	4.0	88.4
		2.0	71.9	10.0	76.8
		4.0	68.4		

Control - seed sown dry.....75.8
Control - seed soaked 2 hours in water.....83.0

** Significantly different from the control (seed soaked in water)

B. Analysis of Variance - Weight of Hypocotyls at Market Size. Greenhouse Trial.

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	55	21325.5		
Replicates	3	461.2	153.74	.52
Treatments	13	9229.0	709.92	2.38*
Error	39	11635.2	298.34	

* Exceeds the 5% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 24.70 gm.
P. (.01) = ± 33.06 gm.

APPENDIX IV

A. Mean height in cm. of new top growth from hypocotyls in cool storage five weeks. Greenhouse Trial.

Seed treatments		Foliage treatments		Root treatments	
		Early		Early	
Rate % conc. hours	Height in cm.	Rate lb. per acre	Height in cm.	Rate lb. per acre	Height in cm.
0.01/½	6.9	0.1	12.4	0.1	9.4
0.02/2	9.7	0.5	7.7	0.5	11.0
0.20/2	8.2	1.0	6.0*	4.0	7.0
		2.0	6.3*	10.0	3.0**
		4.0	2.8**		

Control - seed sown dry.....9.0
Control - seed soaked 2 hours in water.....10.0

Significantly different from the control (seed soaked in water)
* at the 5% level
** at the 1% level

B. Analysis of Variance - Height of New Top Growth. Greenhouse Trial. (Four replicates, six plants per plot).

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	55	596.09		
Replicates	3	14.30	4.77	.93
Treatments	13	382.95	29.46	5.77**
Error	39	198.83	5.10	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 3.24 cm.
P. (.01) = ± 4.32 cm.

APPENDIX V

A. Mean weight in grams of new top growth from hypocotyls in cool storage four weeks. Greenhouse Trial.

Seed treatments		Foliage treatments		Root treatments	
		Early		Early	
Rate % conc. hours	Weight in gm.	Rate lb. per acre	Weight in gm.	Rate lb. per acre	Weight in gm.
0.01/½	9.73	0.1	10.13	0.1	6.48
0.02/2	8.05	0.5	5.40	0.5	8.28
0.20/2	2.68**	1.0	3.05*	4.0	5.53
		2.0	2.10**	10.0	1.25**
		4.0	0.95**		

Control - seed sown dry.....7.03
Control - seed soaked 2 hours in water.....7.70

Significantly different from the control (seed soaked in water)
* at the 5% level
** at the 1% level

B. Analysis of Variance - Weight of New Top Growth, Transformed[1] Data. Greenhouse Trial.

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	55	4.5551		
Replicates	3	.0732	.0243	0.756
Treatments	13	3.2302	.2485	7.740**
Error	39	1.2517	.0321	

[1] Logarithmic transformation of original data was used $Z = (x + 1)$.
** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± .256 units = ± 1.80 gr.
P. (.01) = ± .343 units = ± 2.20 gr.

APPENDIX VI

A. Mean Dynamometer readings[1] made on hypocotyls kept six weeks in cool storage. Greenhouse Trial.

Seed treatments		Foliage treatments		Root treatments	
		Early		Early	
Rate % conc. hrs. time	Lb. pressure per area	Rate lb. per acre	Lb. pressure per area	Rate lb. per acre	Lb. pressure per area
0.01/½	11.03	0.1	8.93	0.1	12.17
0.02/2	11.30	0.5	14.68**	0.5	13.05
[illegible]		2.0	14.70**	4.0	11.03
		4.0	13.50*	10.0	11.40

Control - seed sown dry.....11.73
Control - seed soaked 2 hours in water.....10.20

[1] Readings are in pounds pressure per unit area of plunger head.
Significantly different from the control (seed soaked in water)
* at the 5% level.
** at the 1% level.

B. Analysis of Variance - Dynamometer readings on hypocotyls. Greenhouse Trial. (Four replicates).

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	36	186.79		
Replicates	3	17.23	5.74	1.87
Treatments	11	101.86	9.26	3.01*
Error	22	67.70	3.08	

* Exceeds the 5% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 2.92 lb. pressure per unit area.
P. (.01) = ± 3.95 lb. pressure per unit area.

APPENDIX VII

A. Mean weight of individual roots plus firmly adhering vermiculite as a measure of renewed root growth from hypocotyls in cool storage six weeks. Green house Trial.

Seed treatments		Foliage treatments		Root treatments	
		Early		Early	
Rate % conc. hrs. time.	Ave. wt. in gm.	Rate lb. per acre	Ave. wt. in gm.	Rate lb. per acre	Ave. wt. in gm.
0.01/½	3.46**	0.1	3.30**	0.1	4.01**
0.02/2	3.76**	0.5	1.35	0.5	5.98**
0.20/2	1.65	1.0	0.71*	4.0	0.90
		2.0	0.63*	10.0	0.39**
		4.0	0.35**		

Control - seed sown dry.....3.77**
Control - seed soaked 2 hours in water.....2.10

Significantly different from the control (seed soaked in water)
* at the 5% level.
** at the 1% level.

B. Analysis of Variance - Renewed Root Growth. Greenhouse Trial. (Four replicates).

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	37	79.80		
Replicates	3	1.69	0.56	1.45
Treatments	10	68.87	6.89	17.90**
Error	24	9.24	0.39	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 0.98 gm.
P. (.01) = ± 1.33 gm.

APPENDIX VIII

A. Mean number of days from emergence to first bloom. Field Trial.

Foliage treatments			Root treatments		
	Early	Late		Early	Late
Rate lb. per acre	Number of days	Number of days	Rate lb. per acre	Number of days	Number of days
0.5	43.3	44.3	4	45.3	45.5
4.0	70.3**	45.3	10	45.5	44.0
8.0	70.3**	44.0	20	43.5	43.5

Control.....43.8

** Significantly different from the control at the 1% level.

B. Analysis of Variance - Number of Days to First Bloom. Field Trial. (Ten foot plots, four replicates).

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	51	4733.3		
Replicates	3	14.5	4.8	1.2
Treatments	12	4573.9	47.8	11.9**
Error	36	144.9	4.0	

** Exceed the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 2.9 days
P. (.01) = ± 3.9 days

APPENDIX IX

A. Mean number of days from emergence to full bloom. Field Trial. (Ten foot plots, four replicates).

Foliage treatments			Root treatments		
	Early	Late		Early	Late
Rate lb. per acre	Number of days	Number of days	Rate lb. per acre	Number of days	Number of days
0.5	59.5	58.0	4	57.8	56.8
4.0	78.5**	57.0	10	57.0	57.3
8.0	81.0**	57.0	20	59.0	57.0

Control.....57.5

** Significantly different from the control at the 1% level.

B. Analysis of Variance - Transformed[1] Data, Number of Days to Full Bloom. Field Trial.

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	51	5.71679		
Replicates	3	.00353	.00118	.001
Treatments	12	5.40332	.45028	5.230**
Error	36	.30994	.08609	

[1] Logarithmic transformation of original data was $Z = \log (x + 1)$.

** Exceeds the 1% level of significance.

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± .421 units = ±2.64 days
P. (.01) = ± .564 units = ±3.67 days

APPENDIX X

A. Visual rating (1-10)[1] on the degree of lodging. Field Trial. (Ten foot plots, four replicates).

Foliage treatments			Root treatments		
	Early	Late		Early	Late
Rate lb. per acre	Visual rating	Visual rating	Rate lb. per acre	Visual rating	Visual rating
0.5	7.00	7.50	4	7.75	7.75
4.0	6.50	5.00*	10	6.75	6.75
8.0	5.50*	3.75**	20	7.75	7.00

Control.....7.50

[1] Rating on lodging; 1 = minimum, 10 = maximum.
Significantly different from the control
* at the 5% level
** at the 1% level

B. Analysis of Variance - Degree of Lodging Data. Field Trial.

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	51	143.8		
Replicates	3	6.4	2.13	1.16
Treatments	12	71.3	5.94	3.24**
Error	36	66.1	1.84	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 1.94 units.
P. (.01) = ± 2.61 units.

APPENDIX XI

A. Mean plant height of plots thirteen weeks after sowing. Greenhouse Trial. (Four replicates).

Seed treatments		Foliage treatments			Root treatments		
			Early	Late		Early	Late
Rate & conc. hours	Height in cm.	Rate lb. per acre	Height in cm.	Height in cm.	Rate lb. per acre	Height in cm.	Height in cm.
0.01/½	115.0	0.1	103.0**	119.5	0.1	123.8	132.0
0.02/2	124.5	0.5	103.8**	115.0	0.5	120.0	131.3
0.20/2	96.8**	2.0	65.0**	105.0*	4.0	106.8*	123.8
1.00/2	20.3**	4.0	20.3**	91.3**	10.0	89.3**	118.0

Control - seed sown dry.....121.0
Control - seed soaked 2 hours in water.....128.8

Significantly different from the control (seed soaked in water)
* at the 5% level
** at the 1% level

B. Analysis of Variance - Maximum Plant Height Data. Greenhouse Trial.

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	87	64640		
Replicates	3	647	215.7	1.26
Treatments	21	53240	2535.2	14.85**
Error	63	10753	170.7	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 18.46 cm.
P. (.01) = ± 24.54 cm.

APPENDIX XII

A. Mean plant height of plots twelve weeks after sowing. Field Trial. (Ten foot plots, four replicates).

Foliage treatments			Root treatments		
	Early	Late		Early	Late
Rate lb. per acre	Height in cm.	Height in cm.	Rate lb. per acre	Height in cm.	Height in cm.
0.5	134.0	136.3	4	136.9	143.7
4.0	99.9**	123.8*	10	137.0	146.4
8.0	82.9**	114.7**	20	141.8	138.9

Control.....141.2

Significantly different from the control
* at the 5% level
** at the 1% level

B. Analysis of Variance - Maximum Plant Height Data. Field Trial.

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	51	21247.7		
Replicates	3	74.9	25.0	.23
Treatments	12	17370.0	1447.5	13.70**
Error	36	3802.8	105.6	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 14.7 cm.
P. (.01) = ± 19.8 cm.

APPENDIX XIII

A. Mean total fresh weight of plants from half plots harvested fifteen weeks after sowing. Field Trial.

Foliage treatments			Root treatments		
	Early	Late		Early	Late
Rate lbs. per acre	Weight in grms.	Weight in grms.	Rate lbs. per acre	Weight in grms.	Weight in grms.
0.5	7222	9509	4	6854	6514
4.0	3309**	5458	10	6391	7203
8.0	2793**	4954	20	7027	6573

Control.....7046

** Significantly different from the control at the 1% level.

B. Analysis of Variance - Total Fresh Weight of Plants From Half Plots. Field Trial. (Four replicates).

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	51	261200012		
Replicates	3	1731066	577022	.19
Treatments	12	148673942	12389495	4.03**
Error	36	110795004	3077639	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 2514 grms.
P. (.01) = ± 3369 grms.

APPENDIX XIV

A. Mean air dry weight of whole plants harvested fifteen weeks after sowing. Field Trial. (Ten foot plots).

Foliage treatments			Root treatments		
	Early	Late		Early	Late
Rate lb. per acre	Weight in gm.	Weight in gm.	Rate lbs. per acre	Weight in gm.	Weight in gm.
0.5	2438	2991**	4	2247**	2240**
4.0	994**	2017**	10	2344*	2620
8.0	939**	1935**	20	2445	2370*

Control.....2609

Significantly different from the control
* at the 5% level
** at the 1% level

B. Analysis of Variance - Air Dry Weight of Whole Plants. Field Trial.

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	51	25249186		
Replicates	3	260281	86760	.40
Treatments	12	17101903	1425159	6.51**
Error	36	7887002	21908	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 212.3 gm.
P. (.01) = ± 284.7 gm.

APPENDIX XV

A. Visual rating (1-20)[1] on amount of vegetative growth fifteen weeks after sowing. Greenhouse Trial.

Seed treatments		Foliage treatments			Root treatments		
			Early	Late		Early	Late
Rate % conc. hours	Visual rating	Rate lb. per acre	Visual rating	Visual rating	Rate lb. per acre	Visual rating	Visual rating
0.01/½	13.5	0.1	10.0**	16.3	0.1	11.5	16.3
0.02/2	12.3	0.5	8.0**	16.0	0.5	9.3**	15.8
0.20/2	7.0**	2.0	4.0**	15.5	4.0	6.5**	12.5
		4.0	1.0**	7.8**	10.0	4.5**	15.5

Control - seed sown dry.....13.0**
Control - seed soaked 2 hours in water.....16.0

[1] Rating on amount of growth; 1 = least, 20 = greatest
** Significantly different from the control (seed soaked in water) at the 1% level.

B. Analysis of Variance - Vegetative Plant Growth Data. Greenhouse Trial. (Six plants per plot, four replicates).

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	83	2566		
Replicates	3	109	36.3	3.00**
Treatments	20	1734	86.7	7.17**
Error	60	723	12.1	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 4.92 units.
P. (.01) = ± 5.54 units.

APPENDIX XVI

A. Visual rating (1-10)[1] on the amount of seed pod set fifteen weeks after sowing. Greenhouse Trial.

Seed treatments		Foliage treatments			Root treatments		
			Early	Late		Early	Late
Rate % conc. hours	Visual rating	Rate lb. per acre	Visual rating	Visual rating	Rate Lb. per acre	Visual rating	Visual rating
0.01/½	8.3	0.1	4.8*	6.5	0.1	4.8*	8.0
0.02/2	7.0	0.5	2.8**	6.5	0.5	6.0	7.0
0.20/2	4.8*	2.0	1.5**	4.0**	4.0	2.5**	5.5
		4.0	0.1**	1.3**	10.0	1.3**	4.5*

Control - seed sown dry.....6.8
Control - seed soaked 2 hours in water.....7.3

[1] Rating on seed pod set; 1= poorest, 10= best. Significantly different from the control (seed soaked in water)
* at the 5% level
** at the 1% level

B. Analysis of Variance - Seed Pod Set Data. Greenhouse Trial. (Six plants per plot, four replicates).

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	83	603.6		
Replicates	3	5.6	1.87	0.81
Treatments	20	460.1	23.05	10.00**
Error	60	137.9	2.30	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.01) = ± 2.15 points
P. (.01) = ± 2.85 points

APPENDIX XVII

A. Mean emergence[1] one month after sowing seed collected from treated parent plants. T_1 Generation Trial.

Foliage treatments			Root treatments		
	Early	Late		Early	Late
Rate lb. per acre	Number of plants emerged	Number of plants emerged	Rate lb. per acre	Number of plants emerged	Number of plants emerged
0.5	27.5	23.8	4	31.5	23.5*
4.0	21.3*	4.3**	10	31.0	29.3
8.0	-- --	-- --	20	25.8	26.3

Control.....30.5

[1] Number of plants which emerged from 36 representative seeds sown in greenhouse flats.

Significantly different from the control
* at the 5% level
** at the 1% level

B. Analysis of Variance - Emergence Data. T_1 Generation Trial. (36 seeds sown per plot, four replicates).

Variance due to	D.F.	Sum of Squares	Mean Square	F. value
Total	47	5839.2		
Replicates	3	478.7	159.57	7.08**
Treatments	11	4616.7	419.70	18.62**
Error	33	743.8	22.54	

** Exceeds the 1% level of significance

Least Significant Differences:

L.S.D. (Treatments) P. (.05) = ± 6.83 plants
P. (.01) = ± 9.18 plants